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VOLUME I
FINAL REPORT
FOR
PLANNING ASSISTANCE FOR THE 30/20 GHZ PROGRAM

by G. Al-Kinani, M. Frankfort, D. Kaushal, R. Markham,
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WESTERN UNION TELEGRAPH COMPANY

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. Abstract This volume, Volume I of the three volume Final Report, contains contractor reports (CR) for Tasks 2 and 3 related to the Planning Assistance for the 30/20 GHz Program. Task 2 of Western Union's planning assistance provided to NASA encompassed development of demonstration systems functional requirements based on their experience as a common carrier, and their perception and analysis of 30/20 GHz operational systems functions and capabilities to meet the communication needs in the 1990's. This task encompasses a requirements analysis that develops projected market demand for satellite services by general and specialized carriers, an analysis of propagation and system constraints on 30/20 GHz operation, development of a set of technical performance characteristics which can serve the resulting market, and finally a definition of the experimental program necessary to verify technical and operational aspects of the proposed systems. Task 3 discusses the translation of functional requirements to satellite system technical requirements. In Task 3 multiple concepts proposed by five contractors (TRW, Ford, Hughes, GE and RCA) were reviewed. The multiple concept development efforts were based on a single demonstration flight system. Key constraints on the contractors were cost and the launch vehicle size restricted to SUSS-A or SUSS-D. The outputs of Task 3 are: (1) review of five design concepts, (2) comparison of experiment capabilities, (3) determination of system analysis which need further effort.		
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Task 2 Report - 30/20 GHz Communication System Functional Requirements

Task 3 Report - Planning Assistance for the 30/20 GHz Program; Review of
Specified Conceptual Designs and Recommendations

VOLUME I
EXECUTIVE SUMMARY

1.0 INTRODUCTION

1.1 PROGRAM OBJECTIVES

The Western Union Telegraph Company Government Systems Division was awarded a contract by the NASA Lewis Research Center in May 1980 to provide "Planning Assistance for the 30/20 GHz Program." Major objectives of the planning assistance program were:

- o to develop demonstration system functional requirements based on Western Union's perception and analysis of functions that will be required for an operational 30/20 GHz system.
- o to review and critique Phase II aerospace and new technology contractors design reports and to make recommendations that reflect Western Union's perspective and point of view as a common carrier.

The Western Union inputs were utilized by NASA to help:

- o plan and determine program direction
- o establish system functional and technical requirements
- o guide technology development
- o develop an experiment plan.

1.2 PROGRAM BACKGROUND

The 30/20 GHz Communications System program has been identified as the new start program to re-establish NASA's satellite communication systems and technology research and development posture.

Market demand assessment studies have shown the need for an operational 30/20 GHz communications satellite system during the early 1990's to satisfy

the continued growth in demand for satellite services forecasted to the year 2000. The forecasts reflect that C-band and Ku-band capacity will be saturated during that time frame.

Key NASA objectives for the 30/20 GHz program are:

- o efficient utilization of the radio frequency spectrum
- o development of 30/20 GHz high risk technology
- o demonstration of 30/20 GHz system and technology applicability to commercial satellite services through an experimental flight system.

To ensure that the 30/20 GHz communications system program meets its objectives, particularly that related to commercial service applications, NASA has encouraged active satellite carrier participation through: formation of the Space Technology Applications and Advisory Committee (STAAC); the Carrier Working Group (CWG); under contractual arrangements; and as experimenters utilizing the experimental flight system.

The "Planning Assistance for the 30/20 GHz Program" contract awarded to Western Union on May 1, 1980 resulted from NASA's active effort to have carrier participation. The key objectives of the Planning Assistance Program were identified in Paragraph 1.1.

The "Planning Assistance for the 30/20 GHz Program" contract identified ten task requirements to be accomplished by Western Union. The ten specific tasks were:

1. Task 1 - Carrier Working Group Participation
2. Task 2 - Development of Demonstration System Functional Requirements
3. Task 3 - Translation of Functional Requirements to Satellite System Technical Requirements
4. Task 4 - Review and Critique of Phase II Conceptual Designs
5. Task 5 - Review and Critique of Phase II Detailed Designs

6. Task 6 - Review and Critique of Technology Readiness Status
7. Task 7 - Development of Experiment Program Plan
8. Task 8 - Review and Critique of Options for Demonstration Spacecraft Disposition
9. Task 9 - Review and Critique of the Demonstration System Requirements Documents.
10. Task 10 - Reporting.

In April 1981, the scope of the contract was increased to add an eleventh task, "Worldwide Satellite Market Demand Forecast." The results of the task efforts were submitted to NASA in the form of Task reports, where applicable.

1.2.1 Final Report Structure

This final report for the "Planning Assistance for the 30/20 GHz Program" is contained in three volumes in which the final specific task reports are consolidated. The task reports contained in each volume are:

- o Volume I - Tasks 2 and 3
- o Volume II - Tasks 4, 5 and 6
- o Volume III - Tasks 7 and 9.

Each volume contains an executive summary that identifies the objectives and results of the reports contained in that volume.

Summaries of the Task 2 and 3 objectives and results are given in Sections 1.3 and 1.4, respectively.

1.3 TASK 2 - REVIEW SUMMARY

1.3.1 Objective

The principle objective of the Task 2 study was to define the functional requirements for the NASA 30/20 GHz demonstration system based on Western

Union's perception, as a carrier, of operational system requirements in the 1990-2000 time frame. The study required development of substantial support data leading up to the definition of the demonstration system functional requirements. Considerations included: the projected market demand; traffic mix, flow and distribution; system performance objectives; characterization of the carrier community; and the 30/20 GHz system itself.

1.3.2 Market Assessment

The market analysis used as its basis, previous Western Union, UST&T, and other studies together with additional potential markets identified in the current study. The specific requirements of each type of traffic were then used to arrive at market projections for the Ka-band in terms of the various types of satellite carriers and their market interests: Public carriers carrying primarily switched voice and data between trunking terminals (e.g., AT&T); specialized carriers using primarily CPS terminals (e.g., SBS) to carry voice and data directly between customer locations; and specialized carriers (e.g., WU) which provide both trunking and CPS service. The projected traffic for each of these carriers in the year 2000 has been estimated at 900 GBPS for the public carriers as a group, 200 GBPS for each of two CPS carriers, and 300 GBPS for each of two combination carriers. Based on these estimates, practical limitations on spacecraft capacity, and a balance of initial system costs and long term capacity needs, we estimate that the initial satellite for each type of carrier would have a capacity of 10 GBPS for a public carrier, 2.5 GBPS for a CPS carrier, and 4 GBPS of trunking and 2 GBPS of CPS for a combination carrier.

1.3.3 Network Connectivity

The connectivity problems of the three types of carriers have been analyzed in terms of the requirements of the traffic they carry. A public carrier requires a satellite providing service to points distributed throughout CONUS. A public carrier normally plans its network in advance to integrate all its transmission facilities and can therefore use a predetermined satellite configuration.

A CPS type private carrier is organized to provide corporate or organization-wide networks which are normally isolated from each other. These

networks are constantly changing as a result of customer actions. In many cases some of the user locations will be located in remote areas. Thus a satellite for this type of carrier must have the capability of being reconfigured at high and low rates, and must be capable of reaching any portion of CONUS. (Indeed it is precisely the capability of providing a wide range of broadband services to remote locations that makes a satellite system attractive.)

Combination carriers require both heavy traffic trunking capability and CPS capability. They must therefore have all the features identified above.

1.3.4 Propagation Consideration

The rainfall statistics for the seven rain rate climate zones in CONUS were used to define system power margins needed for various levels of availability for a well-located satellite. The optimum satellite location was determined to be 97°W longitude. A space diversity separation of 8-10 km separation would be sufficient.

1.3.5 Transmission System Considerations

For trunking stations for which a .9999 availability is required, space diversity is necessary, together with a small amount of adaptive power control (4.9 dB uplink and 8.75 dB downlink) and 5 meter antennas. For CPS stations for which .999 availability is required adaptive power control (7.5 dB) and forward error correction is needed except for rain zone E, where it would be necessary to go to lower burst rates, increased antenna size, and more uplink power.

Open-loop synchronization in which slant range calculations are made by the master control station and appropriate delay instructions sent to each trunking or CPS stations is preferred.

An investigation of cross-polarization separation-loss problems indicates that rain-induced depolarization should not affect system performance since the rain induced attenuation will make the signal unusable first.

1.3.6 Functional Specification

The functional specifications for an operational Western Union class carrier 30/20 GHz satellite system has been determined. For trunking, the spacecraft carries 18 fixed $.3^{\circ}$ beams operating at 500 MBPS each. These are interconnected by a fully connected IF switch. Three carrier frequencies are reused six times each.

CPS service uses an additional set of six transponders, each equipped with dual TWT's for the downlink to provide two independent 26.56 MBPS signals at full power. The uplinks will use multiple 32 and 128 MBPS channels. A Baseband Processing Unit will be used to provide full interconnectivity between all CPS users.

1.3.7 Experimental System Functional Requirements

The proposed experimental system would have a 500 MBPS SS-TDMA, a 274 MBPS FDM and an NTSC analog video (36 MHz BW) capability in the trunking mode. Seven beams covering all rain zones would be available, with one steerable beam to measure frequency reuse problems. An on-board TDMA switch would be used for interconnection of the beams, with additional FDM switching between some beam pairs. Dual power (10/75 watt) transponders are required.

Antenna size would be 5 meters for trunking earth stations and 3.5 meters for CPS earth stations (except 5 meters in rain zone E). Uplink power would be 150/450 watts. FEC encoders and decoders ($R=1/2$, $K=7$) would be required in the spacecraft and ground stations for CPS service. A master control station would be required, and full monitoring capabilities should be installed in both the spacecraft and ground stations.

1.3.8 Intersatellite Links

Intersatellite links can be used to provide connections between services (e.g., domestic and international) to reduce the multihop delay. They can also be used to interconnect other band (C to Ku) satellites to a Ka-band satellite. A third

application would be to extend to orbital arc available to Ka-band by using two interconnected satellites for CONUS coverage.

Functional requirements for the intersatellite link are given. From a system standpoint it appears as additional ports on the spacecraft switch and Baseband Processing Unit (BPU).

1.4 TASK 3- REVIEW SUMMARY

1.4.1 Objective

The objective of the Task 3 effort was to review and critique the demonstration system functional design concepts and technical characteristics developed by the Phase II contractors (TRW, Hughes, Ford Aerospace, GE, RCA) relative to NASA Statement of Work requirements and Western Union's perception of demonstration system requirements. Each contractor developed multiple concepts based on a single demonstration flight system. Key constraints placed on the contractors were cost and restriction of launch vehicle size to a SUSS-D or SUSS-A.

1.4.2 General Comments

All the five contractors proposed multiple design concepts. In general, all five contractors meet the minimum NASA Statement of Work requirements for a single demonstration flight. No single concept demonstrates a high degree of scalability to an operational system. Each design concept has significant design advantages whereas certain aspects were lacking. A number of assumptions seem to be made under ideal conditions thereby limiting the potential of the demonstration system. There also appears to be no effort made to be consistent with the sub-systems being developed by other Contractors under the technology development program.

1.4.3 Key Features of Contractor's Design Concepts

1.4.3.1 TRW

TRW has proposed three space segment design concepts. Concept I utilizes a single 4 meter antenna for combined fixed and scanning beam operation. Two identical apertures are employed; one each for the Eastern and Western regions of CONUS. The fixed and scanning beams are orthogonally polarized. This concept employs seven transmit and receive fixed beams, of which only four are active simultaneously. The trunking transmission rate is 512 MBPS per beam. Connectivity between beams is provided by the SS-TDMA switch. In CPS operation there are four channels operating at 32 MBPS and one at 128 MBPS. Connectivity for CPS operation is provided by the baseband processor. Simultaneous trunk and CPS operation is permitted. The ground station sizes for trunk and CPS are 12 and 3.5 meters, respectively.

Concept II is a reduced cost version of Concept I. The receive and transmit apertures are 2 meters and 3 meters respectively. The payload is designed to operate either in four active trunking terminal beams or two fixed beams plus two scanning beams. The satellite power is increased to offset the loss in antenna gain due to smaller aperture. The trunking mode signalling rate is 512 MBPS. The CPS signalling rate is four channels at 16 MBPS and one 64 MBPS. Cross-connectivity between trunking and CPS is provided. Complete connectivity is provided by the IF switch in the trunking mode and the baseband processor in the CPS mode. The ground stations for trunk and CPS are 12 and 3.5 meters, respectively.

In Concept III, the aperture size is the same as in Concept II and functionally they are similar. However, in Concept III, no scanning beams are generated. Instead, a hyperbolic subreflector is used to generate additional fixed beams to provide approximately 20% CONUS. This concept has two modes of operation: four active trunking beams or four active CPS beams. The baseband processor is replaced by an SS-FDMA filter processor for CPS operation. Deletion of variable power dividers for scanning beams and baseband processor results in reduced payload weight. The data rate for trunking mode is 512 MBPS per beam. For CPS mode the SS-FDMA operation provides 144 channels at 64 KBPS, 16 channels at 772 KBPS, and 8 channels at 1.54 MBPS for SCPC transmission. The

ground station sizes for trunking and CPS are 5 meters and 3.5 meters, respectively.

1.4.3.2 Hughes

Hughes has proposed two space segment design concepts. Concept 3 uses a 1.8 meter antenna. Any four beams are active at any one time and complete connectivity is provided by a 4x4 SS-TDMA switch. The burst rate per beam is 128 MBPS. The Customer Premise Service is provided by one scanning beam with 16 positions. The data rate for CPS is 32 MBPS for each of the two channels. This concept also has an optional feature for FDMA transmission using four fixed beams with transmission rate of 128 MBPS. Only one mode, i.e., TDMA or FDMA is allowed at a time. There is no cross-connect between CPS and trunking and simultaneous CPS and trunking is not permitted. The ground station sizes for trunking and CPS are 5 meters and 3.5 meters, respectively.

Concept 4 is essentially an enlarged version of Concept 3. The aperture size is increased to 2.6 meters and trunking beams are increased to 8. Data transmission rate is 128 MBPS. Complete connectivity is provided by an 8x8 IF switch matrix. For CPS service scanning beams are increased to two with two carriers in each beam. The burst rate is doubled to 32 MBPS. As in Concept 3 this concept has FDMA transmission using eight fixed beams at 128 MBPS. The TDMA and FDMA mode can be operated on a non-simultaneous basis. No cross-connectivity is provided between trunking and CPS. The trunking and CPS earth station size is 5 meters. No baseband processor is proposed for either Concept 3 or Concept 4.

1.4.3.3 Ford Aerospace

Ford Aerospace has proposed two concepts. Configuration 1 utilizes an aperture size of 68 inch and 41 inch diameter for transmit and receive. The aperture generates seven fixed beams for trunking pointed at Cleveland, Boston or Miami, Washington D.C. or Houston, Los Angeles or Seattle. Only four of the seven beams are active at any one time. The burst rate is 128 MBPS and complete connectivity is provided by 4x4 IF switch matrix. For CPS service two independently controlled scanning beams are provided. The burst rate for each

beam is 32 MBPS. The ground station size for trunking service is 5 meters and for CPS service the ground station size is 5 meters or 3 meters. No baseband processor is used in this configuration.

In Configuration 2, the antenna and beam characteristics are same as Configuration 1. This configuration also includes two 60 MBPS FDMA channels, a baseband processor and a beacon package for EHF experiment. Simultaneous trunking and CPS operation is allowed in this operation.

1.4.3.4 General Electric Company

General Electric has proposed two configurations. The fixed configuration is the same for both configurations. The transmit and receive apertures are 37 inch and 25 inch respectively. The antenna generates 13 beams to provide complete CONUS coverage. In Alternative A, SS-TDMA, SS-FDMA and a packing switching are proposed. In TDMA trunking mode complete connectivity is provided by a 4x4 IF switch matrix. The transmission data rate per beam is 128 MBPS. In packet switching mode, the connectivity is provided by a 13:1 beam hopper switch. In FDMA mode the transmission data rate is 128 MBPS. NO baseband processing is used for CPS service. Simultaneous CPS and trunking is not allowed and there is no cross-connect between CPS and trunk.

Alternative B is essentially the same as Alternative A. The beam combining is done at IF and SS-FDMA switch is reduced from 13x13 to 6x6. This configuration makes more efficient use of transponder compared to Alternative A and results in reduced weight. The ground station sizes for trunking and CPS service are 5 meter and 3 meters, respectively.

1.4.3.5 RCA

RCA Astro has proposed two concepts. In Concept 1 four fixed beams for trunking and two scanning beams for CPS service are proposed. RCA has proposed to use the antenna subsystem being developed under technology development contracts. The transmission rate for trunking is 256 MBPS and 32 MBPS for CPS service. This concept does not have cross-connect between CPS and trunking

and no baseband processor is used for CPS service. The ground station size for trunking operation is 5 meters and 5 meters or 3 meters for CPS service.

Concept 1A is essentially the same as Concept 1 except additional capabilities in descending order are included. These additional capabilities are: baseband processor, SS-DMA, data rate variation, simultaneous operation of trunk and CPS and eclipse operation.

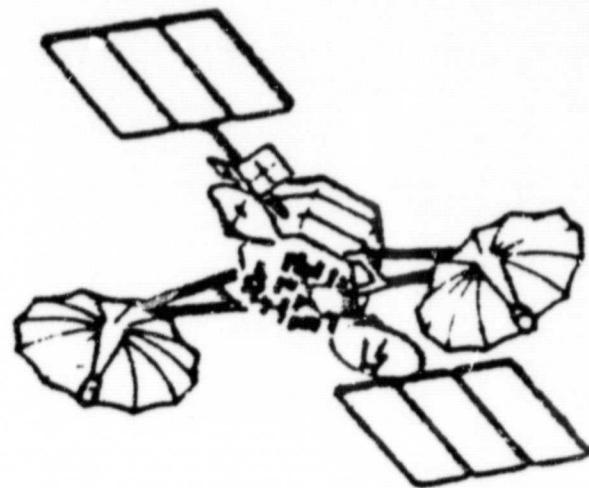
1.4.4 Negative Aspects of the System Design Concepts

In general, the design concepts proposed by all five contractors meet the minimum NASA Statement of Work requirements. However, the following aspects have not been adequately addressed.

1. Although frequency reuse has been demonstrated by all design concepts, far greater frequency reuse will be required to achieve 10 GBPS throughput which is the projected maximum throughput.
2. None of the antenna designs have a steerable beam to evaluate the interbeam interference.
3. The satellite location at 100 degrees west longitude is the optimum location. None of the design concepts has evaluated the impact of satellite location on the availability as the satellite is located towards the extreme positions of the useable arc.
4. Only TRW's Concept I and Ford's design have simultaneous trunking and CPS transmission mode.
5. Although all design concepts meet the margin requirements, none of the design reports have investigated an optimum strategy as related to coding scheme, power control and data reduction.
6. Only TRW has proposed extensive instrumentation for monitoring the performance parameters, however, the impact of such instrumentation on cost, power and weight is not evaluated. None of the other design concepts have proposed instrumentation to monitor the system parameters and performance.
7. Only TRW's Concept I and II, Ford's Configuration II and RCA's Concept 1A have proposed baseband processing for CPS service.

8. Only RCA has made an effort to implement the sub-systems being developed under technology contracts. However, the interface problems of various sub-systems has not been addressed.
9. Hughes and GE have not proposed the use of baseband processor in any of their system designs for CPS service. TRW, Ford and RCA have proposed the use of baseband processor in at least one of their design concepts.

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**TASK REPORT
30/20 GHz COMMUNICATION SYSTEM
FUNCTIONAL REQUIREMENTS**

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EXECUTIVE SUMMARY

1.0 INTRODUCTION

This study defines the characteristics of 30/20 GHz satellite systems to be used in support of projected communication requirements of the 1990's. The study encompasses a requirements analysis which develops projected market demand for satellite services by general and specialized carriers, an analysis of the impact of propagation and system constraints on 30/20 GHz operation, development of a set of technical performance characteristics for the 30/20 GHz systems which can serve the resulting market demand, and finally defining the experimental program necessary to verify technical and operational aspects of the proposed systems.

The market analysis in this study takes as its basis previous Western Union and other reports on the addressable and accessible satellite market demand. Data from these studies, together with that derived from additional potential markets identified in the current study, have been combined and analyzed. The specific requirements of each type of traffic were then used to arrive at market projections for the Ka-band in terms of the various types of satellite

carriers and their market interest. The traffic mix identified for each type of carrier results in a projection of three types of Ka-band satellites: An all trunking satellite, an all CPS satellite, and a satellite combining both types of service.

An analysis of propagation factors at Ka-band identified suitable modes of operation for normal and rain affected operation in each region of the U.S. By combining the market and operation mode studies, a set of functional specifications for a satellite applicable to a Western Union class carrier was established. By comparing these specifications with currently available technology and considering the minimum requirements for a useful satellite system, a set of functional requirements for the proposed experimental satellite was obtained. Such a satellite would be used to investigate presently assumed propagation effects, prove out necessary new technology, and provide an experimental system to assess the applicability of the Ka Band to commercial service offerings.

In addition, certain topics requiring further investigation have been identified, and potential uses of an intersatellite link considered.

Discussion of potential uses of Ka-band satellites normally places great emphasis on the channel availability problem due to weather related attenuation

increases. Methods to resolve this problem require considerable investment in additional hardware, loss of system capacity, and complex control procedures. Without any attempt to minimize the importance of the availability problem at Ka-band, it must be realized that in normal use a Ka-band facility will represent only a part of any entity's total communication capability. Typically a carrier using a Ka-band trunking network will have other trunking facilities as well, be they terrestrial, C-band, or Ku-band, interconnected into a single communication network. Similarly, a company served by a network of CPS stations operating at Ka-band will also have available alternate communication facilities for voice and low to medium speed data via the standard telephone network (message telephone system or MTS). Such alternate routing capabilities for both carrier and private networks are routinely used today in all terrestrial systems.

Examining the Ka-band availability from the standpoint of the user, loss of the Ka-band facility represents a loss of capacity, not a total interruption of communication. (This is not always true for wide band facilities, but most of these are not used for real-time traffic or represent lower priority "real-time" services which can be delayed if necessary.)

Thus the user is faced with either a loss of throughput or increase in blocking probability during a Ka-

band outage, or is forced to use higher cost channels (e.g. MTS), or both. The net result is an increase in cost per unit of traffic. Thus, while the effects of Ka-band outages will certainly be a factor in a decision to implement a Ka-band network, they should not be the overriding factor in determining suitability of Ka-band transmission systems for given services.

A more detailed summary of the report is given below. The sections are keyed to the main sections of the report.

2.0 MARKET ASSESSMENT

The three major traffic categories identified in the previous studies--data, voice, and video--were further broken down on the basis of characteristics affected by Ka-band satellite performance limitations. These are primarily availability and lack of global (CONUS) beam coverage. In later sections of this report, designs for trunking and CPS earth stations are shown which will yield availabilities of .9999 and .999, respectively, over the entire continental United States (CONUS). The lack of full CONUS coverage beams can be circumvented by using simultaneous or sequential transmission on many spot beams. Thus it will be possible to install purely Ka band transmission networks to satisfy any reasonable system requirements. There are, of course, cost penalties involved in these solutions and practical Ka-band

networks may not, in fact, achieve these availabilities or provide CONUS coverage. Notwithstanding these problems we feel that even with significantly lower availabilities than those quoted above, only truly real-time data (e.g. airline reservation systems or credit verification) and Network or CATV broadcast video are completely unsuitable for Ka-band services. As noted in the introduction, other services which at first might seem unsuitable actually can effectively use the Ka band when consideration is given to the other communication facilities available to the user. Thus with overall service quality generated by a combination of Ka-band and other facilities, suitably priced Ka-band links can be attractive in almost any network.

The analysis of existing and announced satellite carriers has identified three types of carriers: public carriers carrying primarily switched voice and data between trunking terminals (AT&T, GTE); private carriers using primarily CPS terminals (e.g. SBS, SPCC, etc.) to carry voice and data directly between customer locations; and combination carriers (e.g. WU and RCA) which provide both trunking and CPS service. The projected traffic for each of these carriers in the year 2000 has been estimated at 900 GBPS for the public carriers as a group, 200 GBPS for each of two CPS carriers, and 300 GBPS for each of two combination

carriers. Based on these estimates, practical limitations on spacecraft capacity, and a balance of initial system costs and long term capacity needs, we estimate that the initial satellite for each type of carrier would have a capacity of 10 GBPS for a public carrier, 2.5 GBPS for a CPS carrier, and 4 GBPS of trunking and 2 GBPS of CPS for a combination carrier.

3. NETWORK CONNECTIVITY

The connectivity problems of the three types of carriers have been analyzed in terms of the requirements of the traffic they carry. A public carrier can use Ka-band facilities to supplement existing lower frequency band facilities, using its existing terrestrial network to concentrate traffic to high capacity trunking stations. It can also use Ka-band to directly connect high traffic points (e.g. downtown city locations), bypassing higher levels in the switching hierarchy. A public carrier would normally require a satellite providing service to points distributed throughout CONUS. This will require either a centrally located satellite or multiple satellites with direct links between them. A public carrier normally plans its network in advance to integrate all its transmission facilities and can therefore use a predetermined satellite configuration.

A CPS type private carrier is organized to provide corporate- or organization-wide networks which are

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normally isolated from each other. These networks are constantly changing as a result of customer actions, both on a long term basis, and dynamically as customer activity varies on a daily or hourly basis. In many cases some of the user locations will be located in remote areas. Thus a satellite for this type of carrier must have the capability of being reconfigured at high and low rates, and must be capable of reaching any portion of CONUS. (Indeed it is precisely the capability of providing a wide range of broadband services to remote locations that makes a satellite system attractive.)

Combination carriers require both heavy traffic trunking capability and CPS capability. They must therefore have all the features identified above.

For all types of carriers the economy of providing CONUS coverage with a single satellite that is, consequently, limited to a small portion of the orbital arc must be balanced against possible improvements in performance obtainable from suitably interconnected satellites with smaller coverage. The problem of orbital arc saturation remains to be addressed.

4. PROPAGATION CONSIDERATIONS

Previous studies of 20/30 GHz propagation have identified seven rain rate climate zones for CONUS. The rainfall statistics in these regions were used to define system power margins needed in each of the re-

gions for various levels of availability and for a well-located satellite. Based on maintaining a reasonable elevation angle over CONUS, the optimum satellite location was determined to be 97°W longitude with a $\pm 7^\circ$ range allowing reasonable operation. An examination of experimental results of earth station space diversity separation vs. expected diversity gain showed that 8-10 km separation would be sufficient to yield considerable system improvements.

5. TRANSMISSION SYSTEM CONSIDERATIONS

The propagation analysis of section IV was used to derive performance requirements for an operating link. The various methods available to increase system margin considered were:

1. Increased Power
2. Increased Antenna Size
3. Forward Error Control
4. Reduced Rate Transmission
5. Space Diversity

For trunking stations for which a .9999 availability is required, no combination of approaches 1-4 will provide satisfactory service. On the other hand, if space diversity is used, a small amount of adaptive power control (4.9 dB up-link and 8.75 dB downlink) and 5 meter antennas are sufficient to provide the availability needed (if diversity gain is obtained on a dB for dB basis for single site fades greater than 18 dB, which requires verification).

For CPS stations, except in rain zone E (southeastern CONUS), with 32 MBPS uplinks and 256 MBS downlinks, the use of adaptive power control (7.5 dB) and forward error correction is sufficient to obtain .999 availability. In rain zone E it would be necessary to go to lower burst rates, increased antenna size, and more uplink power.

A consideration of synchronization techniques has determined that the preferred approach would be an open-loop one in which slant range calculations are made by the master control station and appropriate delay instructions sent to each trunking or CPS station. This will minimize equipment both in the spacecraft and ground stations, as compared to closed loop approaches in which each station determines its own delay.

An investigation of cross-polarization separation-loss problems indicates that rain-induced depolarization should not affect system performance since the rain induced attenuation will make the signal unusable first. There may be some problems with antenna design for cross-polarization (especially in the spacecraft, which has a wide range of beam pointing angles), since maintaining off-axis cross-polarization isolation is harder than obtaining on-axis isolation.

6. FUNCTIONAL SPECIFICATIONS

The functional specifications for an operational

Western Union class carrier 20/30 GHz satellite system have been determined. A requirement for 4 GBPS trunking and 2 GBPS CPS service was assumed. For trunking, the spacecraft carries 18 fixed .3° beams operating at 500 MBPS each. These are interconnected by a fully-connected IF switch. Three carrier frequencies are reused six times each.

CPS service uses an additional set of six transponders, each equipped with dual TWT's for the downlink to provide two independent 256 MBPS signals at full power. The uplinks will use multiple 32 and 128 MBPS channels. A Baseband Processing Unit will be used to provide full interconnectivity between all CPS users.

7. EXPERIMENTAL SYSTEM FUNCTIONAL REQUIREMENTS

Recommendations for an experimental system to provide verification of the propagation analysis and a test of the solutions to the hardware problems and to provide a market trial vehicle are given. The proposed system would have a 500 MBPS SS-TDMA, a 274 MBPS FDM and an NTSC analog video (36 MHz BW) capability in the trunking mode. Seven beams covering all rain zones would be available, with one steerable to measure frequency reuse problems. An on-board TDMA switch would be used for interconnection of the beams, with additional FDM switching between some beam pairs. Dual power (10/75 watt) transponders are required.

Antenna size would be 5 meters for trunking earth

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stations and 3.5 meters for CPS earth stations (except 5 meters in rain zone E). Uplink power would be 150/450 watts. FEC encoders and decoders ($R=1/2$, $K=7$) would be required in the spacecraft and ground stations for CPS service. A master control station would be required, and full monitoring capabilities should be installed in both the spacecraft and ground stations.

8. ADDITIONAL STUDY RECOMMENDATIONS

Areas for further study identified are:

- a) Rain zone E alternative approaches -
Ka-band special design vs. cross-band operation.
- b) CPS mix between semi-permanent and demand assigned channels.
- c) TDMA Synchronization approaches.
- d) Scanning beam vs. Fixed Contiguous beams for CPS.

9. INTERSATELLITE LINKS

Intersatellite links can be used to provide connections between services (e.g. domestic and international) to reduce the multihop delay. They can also be used to interconnect other band (C or Ku) satellites to a Ka band satellite. A third application would be to extend the orbital arc available to Ka band by using two interconnected satellites for CONUS coverage.

Functional requirements for the intersatellite link are given. From a system standpoint it appears as additional ports on the spacecraft switch and Baseband Processing Unit (BPU).

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CANDIDATE SERVICES, MARKET DEMAND, AND
TRANSMISSION CHARACTERISTICS

1.0 STATEMENT OF THE PROBLEM

The requirements of this subtask are to develop a detailed list of candidate services and the following data for each:

- . Performance requirements
- . Availability
- . Transmission characteristics
- . Connectivity requirements
- . Characterization into Trunking/CPS systems
- . Net accessible satellite market for each - forecasted for the years 1990 and 2000.

2.0 INTRODUCTION

To determine whether or not the services identified are viable candidates for 30/20 GHz communication systems, key technical and operational data are established for each as it relates to Ka band operation (e.g., quality and availability). The data is evaluated relative to technical and propagation parameters derived in section 4, as well as operational constraints of a 30/20 GHz communication system, to identify those services that are viable 30/20 GHz candidates and those that are more appropriately suited to "C" or "Ku" band systems.

Previous studies developed forecasts for voice, data, and video service categories. The accessible traffic identified in these studies together with some additional traffic identified in the current study has been used to identify the net accessible trunking and Customer Premise Station (CPS) market size and expected carrier market shares. (Note that a typical CPS user is one with a large transmission capacity requirement located far enough from a trunking station to make it economically preferable to install a separate earth station.)

3.0 METHODOLOGY

The list of candidate services have been developed using the following sources:

- . 18/30 GHz Fixed Communication System.
Service Demand Assessment (WU)
- . 30/20 GHz Fixed Communication System.
Service Demand Assessment (ITT)
- . 30/20 GHz Net Accessible Market Assessment
(WU).
- . Consultation with the Authors of the above.
- . Existing and planned WU services and other common carrier services as understood by WU business planners.
- . Consultation with product line organizations within Western Union.
- . Informal Discussions with representatives from other common carriers.

The reports prepared by Western Union were the result of an exhaustive market research effort that led to the identification of thirty one services that are candidate market applications. The net traffic addressable by satellite systems operating within each of the three satellite frequency bands was then identified. Subsequent effort further developed the accessible demand based on economic justification of facilities implementation by specialized and public common carriers. These reports form the basis for the present effort along with identification of several additional specialized market areas. The resulting accessible market demand was then categorized with respect to: A) common carriers emphasizing different market thrusts; and B) suitability for CPS or trunking requirements.

Technical and operational requirements for each of the candidate services were identified for subsequent comparison to Ka-band system technical and operational characteristics.

4.0 CANDIDATE SATELLITE SERVICES

The thirty one market applications can be segregated into three basic service categories: Data, voice and video. There are 21 applications within the data category and 5 applications in each of the voice and video categories.

4.1

DATA TRAFFIC

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Data traffic may be divided according to its need for immediacy, i.e., real time, packet, and store-and-forward categories. Real-time includes the switched and dedicated traffic, often broadband, where continuous high quality transmission is expected, such as interactive computer service. Although exhibiting real-time characteristics, packet separates users from the medium by nodal intelligence which can:

- (A) Absorb short outages with nodal storage of incoming data;
- (B) Seek alternate routes for longer outages; and
- (C) Defer data transmission when circuits are overloaded due to outage of some of all interconnecting facilities.

Deferred data transmission refers primarily to store-and-forward operation, such as electronic mail, remote job entry, and mailgram/telegram service.

4.1.1 DESCRIPTION OF SERVICE

Satellite services for data transmission will generally require both direct delivery at the customer's premises (CPS), and routing via major trunking stations through local distribution facilities because:

- (A) Customers with CPS stations may need to communicate with customers without CPS terminals.

(B) Operation at much less than the basic 64 Kbps rate through a CPS terminal may be uneconomic (even where CPS terminals exist) compared with a trunking connection.

Those applications requiring distribution among a wide community of users (e.g., switched network data transmission) will predominantly be handled on a trunking basis because many of these users will not be equipped with CPS terminals. Interconnect to CPS users may be provided at major trunking terminals or within the satellite; some considerations for each approach are discussed in Section III. Interconnection with users on trunking systems will be via local terrestrial switching and local loop distribution. Some applications would additionally benefit from interconnection with Terrestrial or C/Ku band links. Data applications frequently include multi-point (e.g., as in polling) as well as point-to-point transmissions. Facilities for both types of operation are required.

4.1.2 PERFORMANCE REQUIREMENTS FOR DATA

Data transmission as defined at the user interface is characterized by the rate, delay, quality of performance and availability of the service. Data rates range from slow asynchronous through 1.544 MB/S for deferred traffic. Real-time traffic is typically at 300 bps to 1200 bps asynchronous at the lower end and ranges from 2.4 kbps to 1.544 MB/S for higher speed

links, some of which will be in support of nodes serving less than real-time (packet) requirements.

One transmission objective (as proposed by Bell's DDS) for real-time high quality data signals is 99.5% error-free seconds when the circuit is available. In general delays due to data traffic outages should not exceed a few seconds for real-time traffic, one minute for packet traffic and one hour for deferred traffic.

Typical availability specifications for high quality real-time data may also be deduced from DDS service end to end availability which is specified at 99.96%. Other data quality specifications have been proposed, e.g., one part in 10^7 error rate for 99.5% of the time with further stipulations as to overall error performance. All of these result in a similar intrinsic quality objective for the end-to-end link of the order of one part in 10^7 with some allowance for burstiness of errors and occasional link down time and/or temporary outages.

In point of fact, many data users currently employ analog facilities which offer considerably poorer performance than the above. It would seem that their major considerations are: A) the price of the service; and; B) the net throughput of the facility under some form of ARQ protection (a common feature of most systems). Most data applications are in fact fairly tolerant of short outages and occasional bursty errors.

4.2 VOICE SERVICES

Voice traffic is conveniently categorized under the following headings:

1. Leased-line business;
2. MTS business (including WATS); and
3. MTS residential.

4.2.1 DESCRIPTION OF SERVICES

Leased-line business traffic encompasses point-to-point service between business locations, usually of the same organization. These services may carry either permanent or switched connections. Another type of leased line service is a connection into the MTS system, e.g., FX lines. MTS business and residential traffic arises from connections to the public switched telephone network directly.

Leased connections between business locations can often be served by CPS to minimize cost by eliminating local distribution. All other voice services would primarily be handled via switches which are best served by interconnection via trunking facilities.

4.2.2 PERFORMANCE REQUIREMENTS FOR VOICE

While it is commonly considered that voice applications require very high availability (99.99%), the requirement can often be circumvented in practice. For example, a portion of circuits forming a trunk group may be unavailable without causing complete loss of service and in non-busy hours there might not

even be a noticeable effect on blocking probability. Thus the apparent availability can be 99.99% even if some of the circuits exhibit much poorer availability. Switched voice traffic requires distribution to a wide community of users. The high degree of connectivity required is most readily achieved via trunking modes. It also implies an interface between users with CPS terminals and those connected to local distribution facilities serving a trunking station. Corporate leased line services often in fact do serve as trunks for private switched systems. For this case CPS terminals will find an important role to play.

Studies of the subjective effects of time delays on speech indicate that the long delays associated with round-trip satellite links are not a serious problem for most users. However, the long-delayed echo accompanying the transmission must be eliminated for service to be satisfactory. Modern echo cancellers are expected to solve this problem. Analog message channel objectives are easily met by standard CODEC's used in the conversion to digital traffic. An error rate better than one part in 10^5 is generally considered acceptable for voice signals.

4.3 BROADCAST TV

Included in this category are Network TV, CATV and special events broadcasts (sports events, etc.).

4.3.1 SERVICE DESCRIPTIONS

The basic requirement of a broadcast TV network is to transmit signals from a source to a large number of users (for example, CATV head ends, television stations or other distribution centers). In addition to services requiring CONUS coverage, new markets are emerging which could require broadcast service of interest to geographically limited areas. These include local news coverage and sports events, public service information, etc., which could be served by a spot beam capability.

The concept of satellite distribution for these service is based upon the elimination of (expensive) terrestrial facilities and therefore this is an almost entirely CPS application, especially for down-links.

4.3.2 PERFORMANCE REQUIREMENTS

Previous studies have assumed a digital 30-50 MBPS bit stream for each video signal. This requires the use of compression equipment which is currently quite costly, especially in view of the need to equip large numbers of receive-only earth stations. Therefore, broadcast television should preferentially use analog transmission to minimize the cost of receive terminals, unless the cost of the compression equipment can be reduced significantly. Availability requirements for broadcast TV are normally extremely high. However, for some special purpose networks, a tradeoff

may be made between availability and cost. Other signal parameters should satisfy NTC 7 standards for network TV, whereas CATV performance may be relaxed somewhat from these standards. For network quality S/N, the NTC 7 requirement is 53dB while 48dB is acceptable for CATV. Limited distribution TV would fall in between these limits. Since obvious picture degradation occurs at 45dB S/N, video links for limited distribution may be designed without fade margin by allowing the spread between nominal operations and obvious degradation to be used instead.

4.4 SPECIAL PURPOSE VIDEO

This consists of some types of videoconferencing, educational and health services, newsgathering, and other applications of video where point-to-point transmission can provide a useful service.

4.4.1 SERVICE DESCRIPTION

There are two types of special purpose video; interactive and one way. Interactive video is represented primarily by videoconferencing. Other forms of "interactive video" require a video return channel, but the request channels use low speed data.

Most other special purpose video is one way to a single point or multipoint.

Videoconferencing via intracompany networks may be satisfactorily served via CPS stations. However, as

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videoconferencing expands toward frequent use of ad-hoc conferences between organizations at least one of which is not equipped for CPS, access to local distribution via trunking becomes more important. In educational video or health networks, newsgathering and other uses of video where geographical flexibility is important, CPS is the preferred mode of transmission because access to wideband local distribution facilities is normally not available.

For special purpose video services there is no time urgency in most cases, so traffic deferral is acceptable. Therefore, availability may not be as important as rapid reconfiguration, geographical area selectivity, and low cost.

4.4.2 PERFORMANCE REQUIREMENTS

Special purpose TV can be divided into full motion and limited motion applications, Educational, medical, newsgathering and full motion videoconferencing require a channel equivalent to broadcast CATV.

Limited motion videoconferencing would be transmitted in a digital mode at 1.5-6 Mb/s. Freeze frame videoconferencing will operate at 56 Kb/s. Both of these can be treated as data traffic but will tolerate poorer error rates--as low as one part in 10^5 .

Because of the data rates involved, freeze frame videoconferencing has been lumped with data traffic in the market analysis.

5.0 KA-BAND MARKET FORECAST

The characteristics of Ka-band transmission are reviewed below and then are used to identify those services which are more amenable to Ka-band satellite transmission. Market forecasts for these services are then derived based upon previous work and potential services that have been identified since the previous study was completed.

5.1 KA-BAND TRANSMISSION LIMITATIONS

There are three inherent characteristics of Ka-band which impact on the utility of a Ka-band satellite for the services described in Section 4:

- . Limited availability
- . Limited Beam Coverage
- . Analog Transponder Penalties

Ka-band services are subject to weather-induced outages, typically of ten minutes duration. These can be countered by diversity operation, power control, and adaptive forward error control or a combination of these techniques. Diversity operation is generally only feasible economically for trunking stations and possibly for broadcast uplinks. Power control is of only partial benefit (approximately 5dB) due to the limited power increases available and the time required to coordinate changes. FEC will result in a trade of available spectrum for more margin. Both of these techniques combined can serve to enhance availability

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for CPS stations through increased margin but will still leave residual outage or partial outage periods. Therefore, in the market assessment which follows, it is assumed that services which cannot tolerate such outages are not prime candidates for Ka-band satellites. As will be described, most services can in fact tolerate such outages and remain candidates for Ka-band transmission.

Limited beam coverage results from the fact that additional power is necessary to transmit at Ka-band compared to the C/Ku bands. Thus services requiring simultaneous CONUS coverage cannot be easily provided.

Services requiring an analog transponder or partial transponder are somewhat limited by the less efficient use of spacecraft transponders for each analog circuit. The number of 36MHz analog transponders which may be placed in a particular spacecraft is limited because of space and power limitations, and will not use the bandwidth fully. However, for multi-ground station applications, efficient transponder utilization may not be of prime importance so that a case can be made for analog transmission (or SCPC for that matter) in a number of cases.

5.2 SERVICES ADAPTABLE TO KA-BAND TRANSMISSION

5.2.1 DATA

Of the three types of data delineated in section 4.1,

i.e., real-time, packet, and deferred traffic, deferred traffic is more amenable to Ka-band transmission than the other two. However, there may be users of some "real-time" services who are willing to tolerate occasional outages if the cost of the service is attractive. Similarly, packet networks using Ka-band satellite facilities may be able to cope with occasional outages and/or reduced capacity by virtue of intelligence in the nodes which will to some extent mask these effects from the user. Almost all data is point-to-point, or point to a defined set of other points and therefore is not affected by the lack of simultaneous CONUS coverage.

5.2.2 VOICE

For a public carrier trunking system carrying a small percentage of a trunk group on a Ka-band satellite, only a small penalty (in blocking probability) would be incurred during an outage, and this only if the outage coincides with a busy hour. Thus, a lower cost voice channel could be attractive. The same considerations apply to private lines wherever a significant cross section between two points is provided. The following should be noted with respect to Ka-band voice circuit unavailability for private networks.

- A) In many corporate networks, serving trunk groups are undersized for economic reasons so that blocking probability is already high during peak periods. Lack of facilities arising from inclement

weather would thus only extend such high blocking periods affecting service in a similar manner to an unexpected additional load.

- B) Where facilities are mixed, one generally has recourse to alternate means of transmission. For example, if intra company tie lines are unavailable due to overload or outages, alternate paths are normally available via MTS. This results in additional costs during Ka-band outage and it will be necessary to develop an economic profile to decide just what the most cost effective combination of facilities would be. Under a scenario in which Ka-band facilities offer significant economic advantage these should dictate their use despite occasional outages.
- C) Outages for Ka-band will be area limited, so that an adjacent serving area may be able to communicate. Alternate routing via adjacent facilities coupled by terrestrial facilities could therefore greatly alleviate local circuit outages.

In view of the above it would seem that voice Ka-band services whether by CPS or trunking facilities can be readily sold if the price advantages can be realized. Voice is almost never broadcast and therefore is not amenable by spot beam coverage.

5.2.3 BROADCAST TV AND CATV

The TV network and CATV distribution markets have limited ultimate growth capabilities and an already heavy investment in C-band facilities. In addition, except possibly for a few marginally profitable CATV services, Ka band outages are not tolerable for these markets. Limited beam coverage will also make Ka-band transmission unattractive to users with a nation-wide coverage requirement.

Limited area networks, one of the new services identified in this report, would probably tolerate short outages if the overall service cost were low enough. The limited beam coverage at Ka-band is an advantage in this case, allowing extensive frequency re-use. Broadcast TV normally favors the use of analog transmission to minimize the cost of TV receiving equipment. Therefore, due to the analog transponder limitations, effective satellite costs may increase for this type of service offering.

5.2.4 SPECIAL PURPOSE VIDEO

These services would tolerate outages if the cost is sufficiently attractive.

The small coverage afforded by spot beams is of no consequence, since these are basically two point services. Full bandwidth video would be easier to handle on an analog basis. Low bandwidth video is almost always digital.

5.3 MARKET FORECASTS

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5.3.1 BASIS FOR MARKET FORECASTS

The 18/30 GHz Demand Assessment effort developed base-line total market forecast for the data, voice, and video service categories. The baseline forecasts were modified in successive processing steps to develop impacted baseline, net long haul traffic, addressable and accessible satellite market forecasts. During the current study, certain additional services were identified as viable candidates for Ka-band satellite systems. Traffic was estimated for these new services to obtain a total market forecast. The revised market forecasts will be described in terms of two typical carrier traffic scenarios: public carrier and specialized common carriers. The public carriers currently address the voice MTS market primarily while specialized common carriers currently address all major market areas including private line voice, video and data.

5.3.2 NEW SERVICES IDENTIFIED

The new services (all in the video area) are:

- . Video Data Retrieval
- . Limited Area TV Distribution
- . TV Newsgathering

A video data retrieval service has been identified in which video data banks containing current information of primary importance to various industry, institutional, and government groups, can be accessed by an

authorized user. Typical examples would be rare medical procedures for doctors, new analysis procedures for chemists, and repair procedures for complicated electronic or mechanical equipment. The transmission would be on a simplex basis from the data base to the user. Communication for inquiry can be accomplished via either a telephone or a low or medium speed data channel.

Limited area TV distribution would be used for broadcasting local sport or public affairs events to an area lying within a spot beam region.

Temporary video uplinks for newsgathering and similar purposes can be established in the Ka-band without the coordination problems encountered at C band which would very helpful in rapid establishment of such uplinks. This is a point-to-point TV service.

5.3.2.1 MARKET CONTRIBUTIONS FROM NEW SERVICES

Video data retrieval will compete with direct distribution of video information via tape cartridges and video discs. The market potential is thus hard to quantify. As a first attempt, a requirement for six channels has been assumed.

Limited area TV distribution is a potential market whose growth is likely to be highly cost sensitive. The use of satellite capacity installed primarily for other services will thus be very attractive. For these reasons the number of additional transponders

estimated to be needed for this service has been estimated as ten.

Temporary video uplinks would be used for transmission from locations where permanent facilities were unavailable. Considering the number of users of such services and the number of simultaneous events requiring such facilities, a requirement for ten satellite channels would seem to be a good estimate.

All these services would use spot beams to CPS type earth stations.

5.3.3 PUBLIC CARRIER

Public carriers currently address the voice MTS market primarily and also a portion of the data between different business establishments. These carriers presently operate exclusively in a trunking mode.

Services provided by the public carriers, e.g., AT&T and GTE, are heavily influenced by the large investment they have in terrestrial plant. Therefore, Ka-band trunking by public carriers would be backed up by terrestrial facilities, resulting in an acceptable level of availability. Business and residential voice services are therefore prime targets for transmission over Ka-band trunks that have been integrated with alternate routing facilities (or that are provided using space diversity terminals).

Based upon present thinking, it is unlikely that public carriers would get significantly involved with

CPS. This is not only from a technical point of view, but because they own the existing local distribution plant.

Newer services such as wideband 1.5-6.0 Mb/s videoconferencing could be captured by public carriers using Ka-band satellites in the trunking mode since the public carriers are expected to have extensive wideband local distribution within this time frame. Narrowband videoconferencing (56 kBits/s and under) will also readily be carried on local distribution networks. It is expected that, in the long term, videoconferencing would benefit from the trunking mode which permits on-demand videoconferencing between unrelated organizations.

5.3.4 SPECIALIZED COMMON CARRIER

Specialized common carriers currently address all major market areas including private line voice, video and data. Despite initial system designs directed toward voice transmission, the dominant satellite service business of the specialized carriers is video and program distribution services where the point to multipoint transmission capabilities of existing satellites are most effectively realized. However, a strong interest in the business and government voice and data market has been maintained and the projections for growth of this type of traffic will assure

that this market will dominate in the time frame of interest for Ka-band satellites. Although the degree of flexibility in routing enjoyed by public carriers with respect to voice and data will not be as great for the specialized carriers, it will be possible to mitigate the effects of outages in much the same manner (e.g., through a mix of transmission media and adaptivity) and by use of the public networks as an alternate transmission medium. Since much business voice traffic is in fact used for trunks between PABX's or tandem switches, outages will have the same effect as increased traffic loads. Under conditions of a properly designed system, the specialized carriers should thus be carrying appreciable amounts of voice traffic on Ka-band satellites. Specialized carriers will use both the trunking and CPS modes in support of voice and data traffic.

The previously completed 18/30 Accessable Market Study tabulated primary and secondary areas of interest for potential specialized common carriers. Based on this, one class of common carrier has been postulated as represented by either RCA, or Western Union with American Satellite (who has long term arrangements for joint use of the satellite). Another class, emphasizing different market areas, would be a SBS or XTEN type of carrier.

5.3.5 MARKET SHARE ANALYSIS

Based upon the foregoing, the assumption is that there will be three types of carriers providing Ka-band satellite service: Public carriers, Western Union/RCA-type specialized common carriers and the SBS/XTEN-type specialized common carriers. Examination of the WU 18/30 GHz Demand Assessment effort and other sources, such as the SBS filing in support of its application for satellite service, provided the basis for making the assessment of probable carrier market share in the year 2000 as shown in Table 5.3.5-1.

As noted in Section 5.3.3 it has been assumed that no CPS service will be offered by a public carrier. It has also been assumed that SBS/XTEN-type carriers will not offer trunking service. In addition, based on current market trends, it is expected that full bandwidth video will be provided only by an RCA/Western Union-type carrier.

(As noted previously, slow motion videoconferencing is considered as being a data service). The CPS/trunking split for other services was obtained by comparing the SBS traffic predictions with the WU 30/20 GHz Accessible Market study. The trunking split between public and specialized carriers is based upon current market trends. For example, public carriers handle more low speed than high speed data. Division of traffic between carriers in the same category e.g., SBS/XTEN was assumed 50/50.

<u>Service</u>	<u>Public Carrier</u>	<u>Western Union</u>		<u>RCA</u>	<u>SBS</u>		<u>XTEN</u>
	Trunking	CPS	Trunking	CPS	Trunking	CPS	CPS
Broadcast Video	---	50	---	50	---	---	---
Special Video	---	35	15	35	15	---	---
Full Bandwidth	---	16	8	16	8	24	24
Limited Motion	4	4	10	4	10	6	6
Voice	60	16	5	16	5	24	24
Data	10	10	10	10	10	10	10

Table 5.3.5-1

Market Share for Satellite Carriers - Percent of total Accessible Market.

The service split between types of specialized carriers, i.e., Western Union/RCA vs. SBS/XTEN is based upon the primary/secondary market determination made in the 30/20 GHz Accessible Market study. Sixty percent of the traffic was assigned to primary carriers with the remainder assigned to the secondary carriers. The number of transponders for satellite carriers were calculated from total traffic estimates obtained from the 30/20 GHz Net Accessible Market Study, the SBS satellite filing, and new services identified in Sec. 4. Dividing this traffic among the various carriers using Table 5.3.5-1 resulted in Table 5.3.5-2. The calculations assumed an equivalent transponder providing 50 Mb/s for voice or data or one full-motion video channel. (Note that splitting the analog transponders among the satellites results in about six analog transponders/satellite, which appears practical.) Conversion of transponder capacity to number of satellites involves both technical and economic problems. At the technical end, while total capacity for a trunking satellite is relatively easy to determine from the Hughes and TRW Phase I reports, the reduction in capacity due to the introduction of CPS is much less clear. It will depend on the method of operation (TDMA or FDMA), the manner in which spot beams are interconnected, etc.

From an economic standpoint it is quite likely that

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<u>Service</u>	<u>Public Carrier</u>	<u>Western Union</u>		<u>RCA</u>		<u>SBS</u>		<u>Xten</u>
	Trunking	CPS	Trunking	CPS	Trunking	CPS	CPS	
Broadcast Video	---	13	---	13	---			
Special Video								
Full Bandwidth	---	3	2	3	2			
Limited Motion	14	56	28	56	28	84	84	
Voice	660	44	110	44	110	66	66	
Data	22	35	11	35	11	53	53	
TOTAL	894	151	149	151	149	203	203	
		300	;	300	;			
No. of Satellites	18	6	6	6	6	4	4	4

Table 5.3.5-2

Transponders for Satellite Carriers

when service is first established the traffic requirements will be much less than those projected here. It may well be that under such circumstances a lower than possible capacity satellite will prove to be optimum, especially if the savings in space and weight of the communications system can be used to extend the useful life of the spacecraft, modify the performance to reduce earth station costs, or similarly improve over all system performance, as well as reduce initial costs. Additionally, because of the range of variation possible in synchronization techniques, beam scan patterns, channel assignment algorithms, etc., it is unlikely that a single satellite could serve the needs of more than one carrier. This also favors the use of lower capacity satellites since the available customer base will thus be fragmented.

The above considerations will be least applicable to a public carrier, since a trunking system permits the use of a much simpler satellite, and since a public carrier is in a better position to switch a large amount of traffic to Ka-band at one time. We have therefore assumed a 10 GBPS capacity for a public carrier satellite. On the other hand, the size of a SBS/XTEN type satellite will be heavily influenced by the above considerations, and we consider 2.5 GBPS a reasonable size for the initial satellites and 5 GBPS for later models.

U/RCA type satellites would be sized at an intermediate level, for example 4 GBPS for trunking and 2 GBPS for CPS, on the initial satellite, with a heavier emphasis on CPS in subsequent satellites (i.e. 3.5 GBPS for trunking and 5.5 GBPS for CPS).

An examination of Table 5.3.5-2 shows that the three types of satellites may be distinguished not only by the types of service offered but by configuration--all trunking, all CPS, or combined trunking/CPS. It is clear that enough traffic has been identified to justify market entry by each of the assumed carriers, even if the aggregate traffic demand were to fall considerably short of the projected levels.

III

NETWORK CONSIDERATIONS

1.0 STATEMENT OF PROBLEM

To develop typical network topologies, traffic mix, loading and connectivity for a trunking/CPS carrier such as Western Union.

2.0 INTRODUCTION

Two basic types of network are examined, i.e., public and specialized carrier. The public network, exemplified by the Bell system, will offer Ka band satellite services as an adjunct to its terrestrial network, using the additional capacity provided by the Ka band system to augment existing terrestrial facilities. In a specialized carrier network, typical of the type operated by Western Union, limited terrestrial distribution is available for use with the Ka band satellite system.

Connectivity requirements will be described below for each service category expected to be offered by Western Union using Ka band satellite transmission in terms of traffic and performance requirements, service mode (CPS or trunking), and the necessary service availability. Aspects of connectivity explored are the number of satellites and transponders per satellite, the number of spot beams, the probable geographical distribution of service and the need for interconnection with terrestrial and other satellite systems. The impact of advanced satellite technology (e.g. multibeam and multiple

satellite systems) on the achievement of connectivity requirements is discussed.

Satellite capacity and distribution requirements for typical Western Union Network topologies are described. These topologies are related to the growth of specialized carrier traffic, starting from an initial minimum feasible satellite network to a maximum one predicted for the year 2000. This analysis predicts that the cumulative portion of this market ranges from 30 to 84 percent of the net addressable satellite market, depending on the number of SMSA's addressed.

3.0 METHODOLOGY

The typical network topologies described are based upon information from the following previous studies:

- 18/30 GHz Fixed Communication System Service Demand Assessment (W.U.).
- 30/20 GHz Net Accessible Market Assessment (W.U.).
- Propagation Effects Handbook for Satellite Systems Design (NASA).

They are based upon a detailed market research effort that led to the identification of thirty one services that are candidate satellite markets, augmented by the following three additional market areas:

- Video Data Retrieval
- Limited Area TV Distribution
- TV Newsgathering

Each candidate service was examined in turn, and the connectivity requirements expected to satisfy most users of that service is described below:

4.0 ANALYSIS

4.1 TYPICAL NETWORKS FOR PROVIDING KA-BAND SERVICE

Two types of networks may be visualized for providing Ka-band service. These two types of network may be conveniently categorized as either public or specialized, each of which is described in relationship to its application as a Ka-band network.

4.1.1 PUBLIC NETWORK

This refers to a network approach likely to be implemented by a dominant carrier such as AT&T which has a very extensive existing terrestrial network. The Ka-band satellite services would be offered as an adjunct to their terrestrial network, using the additional capacity provided by the Ka-band system to augment existing terrestrial facilities. A public network of this type is likely to consist of a limited number of high volume earth station locations, each serving a large geographical area. Each earth station would serve a region containing a number of large, medium and small size cities, or one or more SMSAs (Standard Metropolitan Statistical Areas).

4.1.2 SPECIALIZED NETWORKS

4.1.2A TRUNKING NETWORK

These networks have more limited terrestrial distribution systems, primarily used for interconnecting with the Ka-band satellite system. In this type of network a number of earth stations are strategically located closed to the major areas of market demand. As before, each earth station location serves a central SMSA, with terrestrial extension to other SMSAs. Terrestrial extensions are used to assemble enough traffic to provide a viable network, but for economic reasons are generally limited to a radius of about 50 miles from the earth station. Earth stations may be small, medium, or large, depending upon the type and quantity of projected traffic. A network of this type is appropriate to the Western Union environment.

4.1.2B CPS NETWORKS

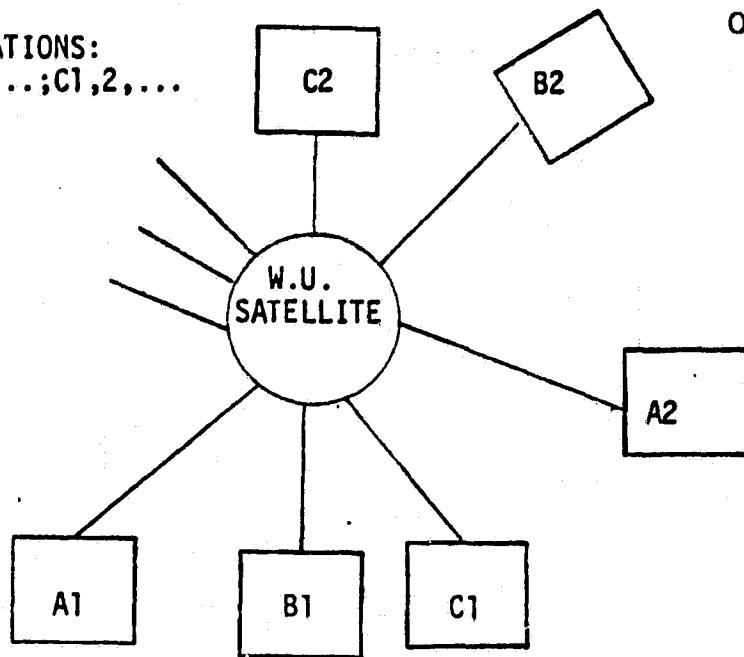
Two possible CPS network configurations are visualized, as illustrated in Figure 4.1.2-1:

- (a) Intra-organization CPS links; and
- (b) CPS links subleased by other carriers.

In the intra-organization type of communication network, illustrated in Figure III-1A, large companies and government organizations lease capacity from a satellite common carrier (e.g., Western Union) to interconnect geographically widely dispersed offices having high traffic volume requirements. Each office

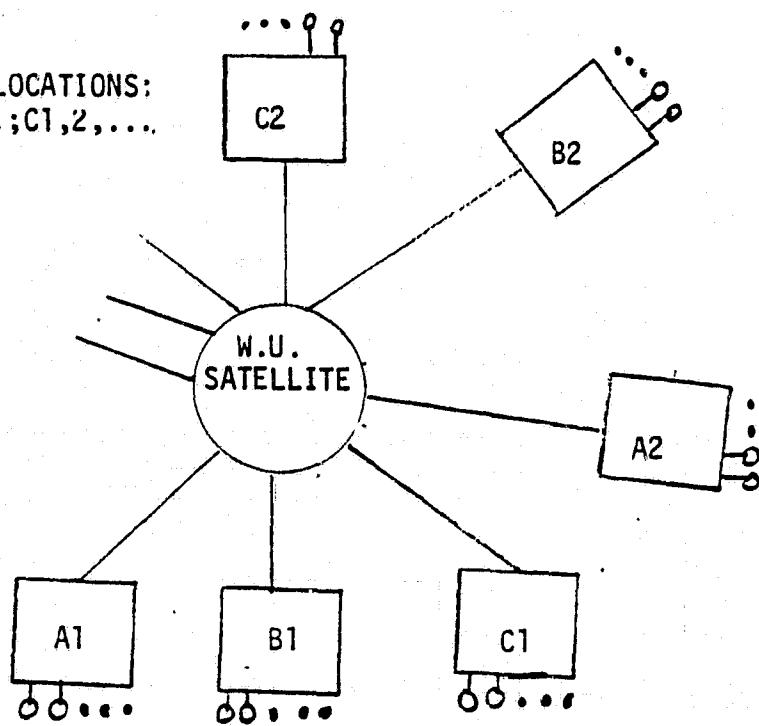
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ORGANIZATION LOCATIONS:
A₁, 2,...; B₁, 2,...; C₁, 2,...



(a) INTRAORGANIZATION CPS LINKS

OTHER CARRIER CPS LOCATIONS:
A₁, 2,...; B₁, 2,...; C₁, 2,...



(b) CPS LINKS SUBLICENSED BY OTHER CARRIERS

FIGURE III - 1 POSSIBLE CPS CONFIGURATIONS

has associated with it a separate ground station for communication to the satellite, which links the ground stations. Interconnection between the CPS network and other networks is performed at the ground stations.

Sublease by a satellite common carrier (e.g., Western Union) to other specialized carriers (e.g., Tymnet) for satellite capacity sharing to its customers is shown in Figure III-1B. In this case the CPS ground stations act to concentrate traffic from a number of users at each ground station, which are interlinked via satellite. While the carriers A, B & C are providing a trunking service, Western Union is supplying dedicated CPS service to the second tier carriers.

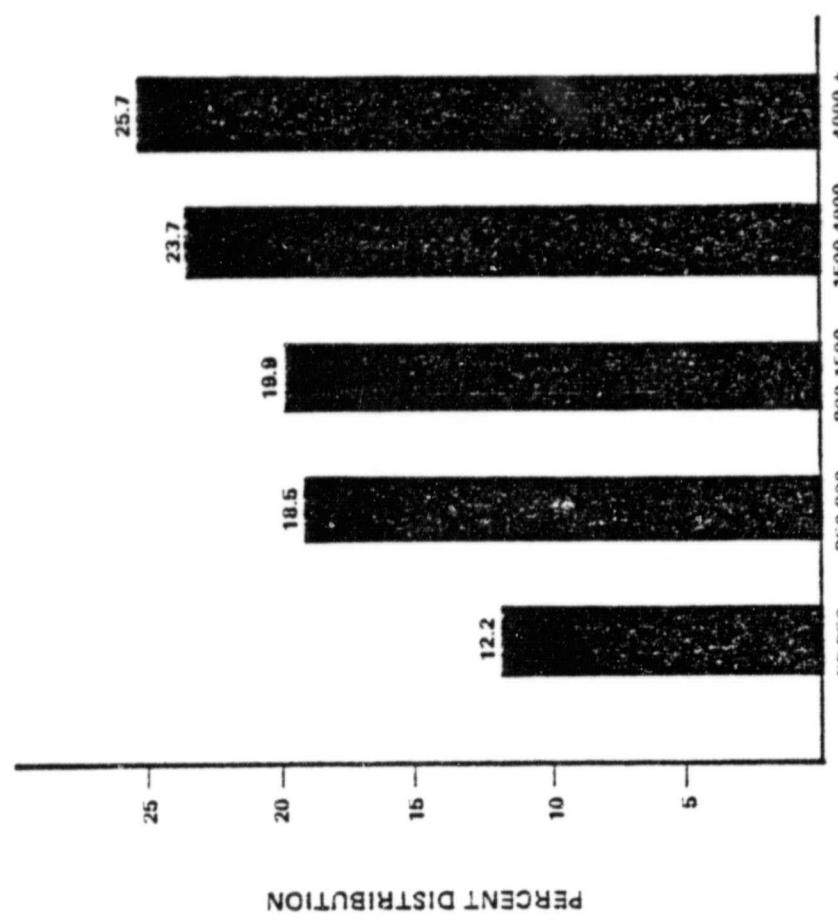
4.1.3 GEOGRAPHIC TRAFFIC PATTERNS

The installation of a trunking Ka-band satellite system by a carrier is based upon an estimate that this system will augment its existing trunking network in a cost effective manner. In the case of a public carrier, the satellite system relieves a portion of any traffic peaks which would tend to overload the existing terrestrial network, or it may be used to provide new services not conveniently handled by the terrestrial network in a cost effective manner (e.g., video-conferencing). A specialized carrier might use a Ka-band trunking system to provide service capacity not currently available with its existing limited network. Therefore, a geographic study of traffic patterns and

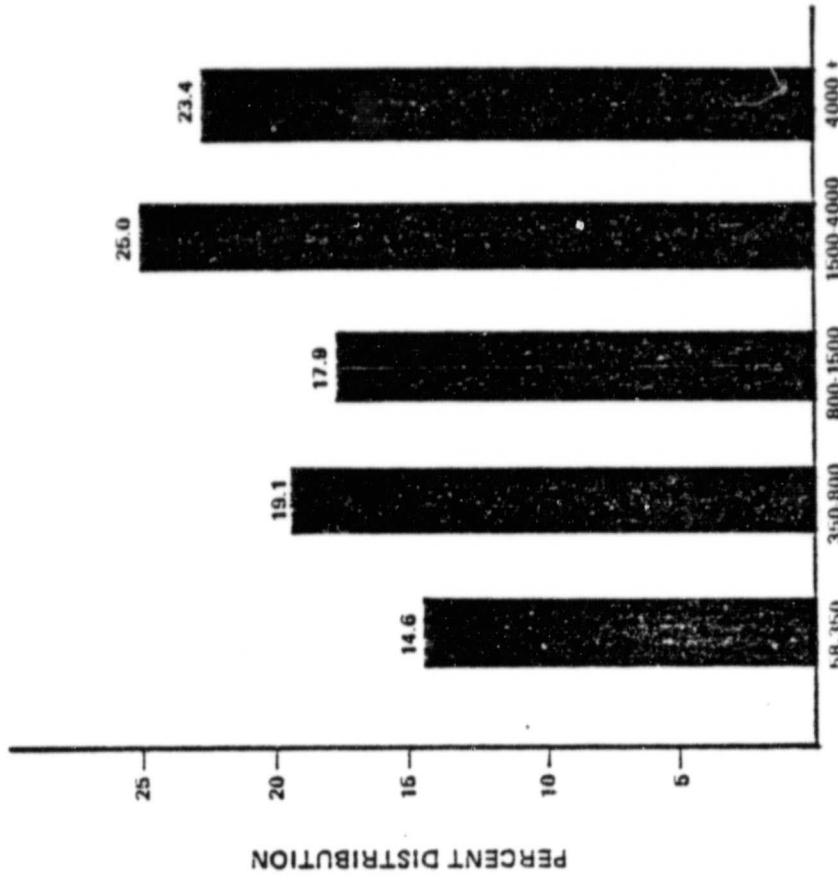
the interconnectivity requirements of services are important considerations in determining where earth stations should be located and how they should be interconnected. An estimate of geographic patterns may be obtained from a Western Union study,⁴ used to obtain a service demand assessment.

In the studies, traffic volume was estimated by service category as a function of city size, based upon 275 SMSA's grouped into five population categories. Each population category was assigned to a minimum/maximum range that produced five population groupings (quintiles), each with approximately 20% of the total SMSA population (157.3 million). The percentage proportions of the market demand for voice and data traffic by SMSA were determined and assigned to the appropriate population quintile, using weighting factors to indicate the relative importance of market demand per unit population within each SMSA. The distribution of voice and data traffic volume by population quintile, developed in this manner, is presented in Figure III-2. A video service category is not included since a substantial portion of video traffic is broadcast in nature, originating in a limited number of cities and received throughout the CONUS. This is consistent with Section II - 5.2.3, where it was concluded that this service category is not suitable for Ka-band since the TV network and CATV

VOICE SERVICES



DATA SERVICES



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FIGURE III - 2

TRAFFIC DEMAND/POPULATION DENSITY
1990

distibution markets already have heavy investment in C-band facilities and Ka-band does not provide the reliability required for this service.

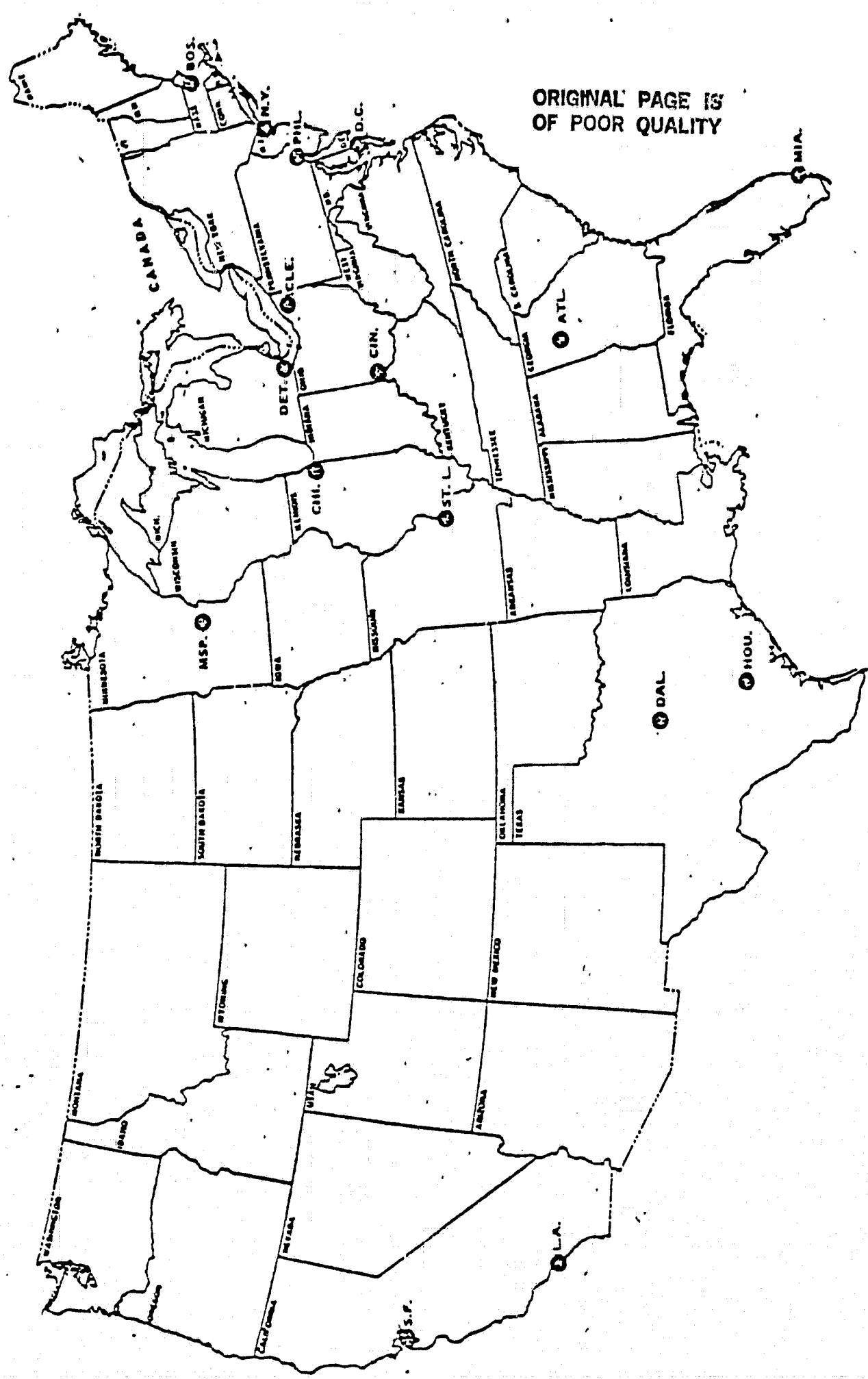
Note that the top 15 SMSAs, having populations ranging from 1.5 to 4+ million, have a predicted demand of 49.4% of the total voice traffic and 48.4% of the total data service for 1990.

Analysis of the economics of operating a communications network in the U.S. indicates that about 30% of the accessible market represents the minimum viable market that a satellite network must serve to attract a sufficient number of customers and subsequent traffic load to its network. Based upon the SMSA population distribution, this coverage will be achieved by addressing the population centers illustrated in Figure III - 3. Therefore, this minimum network will serve as a basis for estimating the traffic requirements for establishing a specialized carrier Ka-band network.

For accurate prediction of the geographic location of CPS networks, a study is required to determine the geographic distribution of the high volume traffic centers for large industrial and government organizations. An estimate of the total CPS networking market size may be obtained by examining the users of long haul traffic. A determination of the major segment of the user population for large organizations was part

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FIGURE III - 3 FIFTEEN TOP SMSAS PROVIDING 33% MARKET COVERAGE FOR YEAR 1990



of the service demand assessment study. A quintile distribution of user population in each user category by traffic volume was obtained from the Fortune Double 500/50 directory, a federal government department and agency list, and a list of major city/local governments, institutions of higher learning, and major hospitals. The conclusions of this study are:

1. About 1,000 (less than .05% of the over 3 million business firms) represent 60% of this category's total transmission expenditures with an average annual transmission expenditure of \$4.6 million.
2. Only 19 federal departments (of the total of 84 departments and agencies), each spending \$12.0 million per year or more on telecommunications service, make up 80% of the federal governments' total transmission expenditure.
3. All state governments, except for Wyoming, and the 18 largest city governments spend over \$1 million each on telecommunication services.
4. The larger institutions of higher learning and hospitals have average annual transmission expenditures of \$229,000 and \$185,000, respectively.

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Table III-1 summarizes some typical statistics of organizations which may be candidates for CPS networks. A typical large company is estimated to have four major locations, resulting in annual telecommunication expenditures in excess of \$5 million per location. A typical Federal agency having 20 locations would spend in excess of \$40 million per establishment. At the state level, over \$2 million would be spent per establishment, and over \$.5 million at hospitals and schools.

	Number of entities	Average yearly expenditure (\$000,000)	Number of locations per entity	Average yearly expenditure per location (\$000,000)
LARGE CORP.	1550	20.8	4	5.2
FED. AGENCY	19	861.8	20	43
STATE GOVERN.	65	6.4	3	2.1
HOSP. & SCHOOLS	1000	.6	1	.6

TYPICAL USER LONG HAUL TRANSMISSION EXPENDITURES--YEAR 2000

TABLE III-1

An estimate of the point at which it might pay for an organization to acquire a CPS earth station may be obtained by calculating the required savings, S, of telecommunications cost using a CPS mode relative to competing service:

$$S = 1 - E/TC$$

where:

E = one-time earth station cost,

C = transmission expenditure/yr. of a typical establishment

T = 5.33 = 10 year amortization period discounted at 20%/yr.

Equation 1 is plotted in Figure III-4 for earth station costs ranging between \$1,000 and \$1,000,000. As illustrated, a large establishment expending one million dollars per year would break-even at virtually no cost reduction if a \$100,000 earth station is used and would require only a reduction to 90 percent of other facility long haul transmission costs to justify the use of CPS with only one-half of this traffic carried by the CPS terminal.

At the lower extreme, schools or medical establishments with typical annual long haul communications expenditures of \$0.6 million (of which one-half was adaptable to a CPS system) would have to receive a 75 percent reduction in annual costs before a \$1 million earth station could be justified but would need a reduction to only 90 percent to justify a \$100,000 earth station.

Thus, earth station costs in the range of \$100,000 to \$1,000,000 appear justifiable to a wide range of potential user organizations who, assuming acceptable quality of service, will find CPS networks a viable

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SEMI-LOGARITHMIC CYCLES x DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

46 623

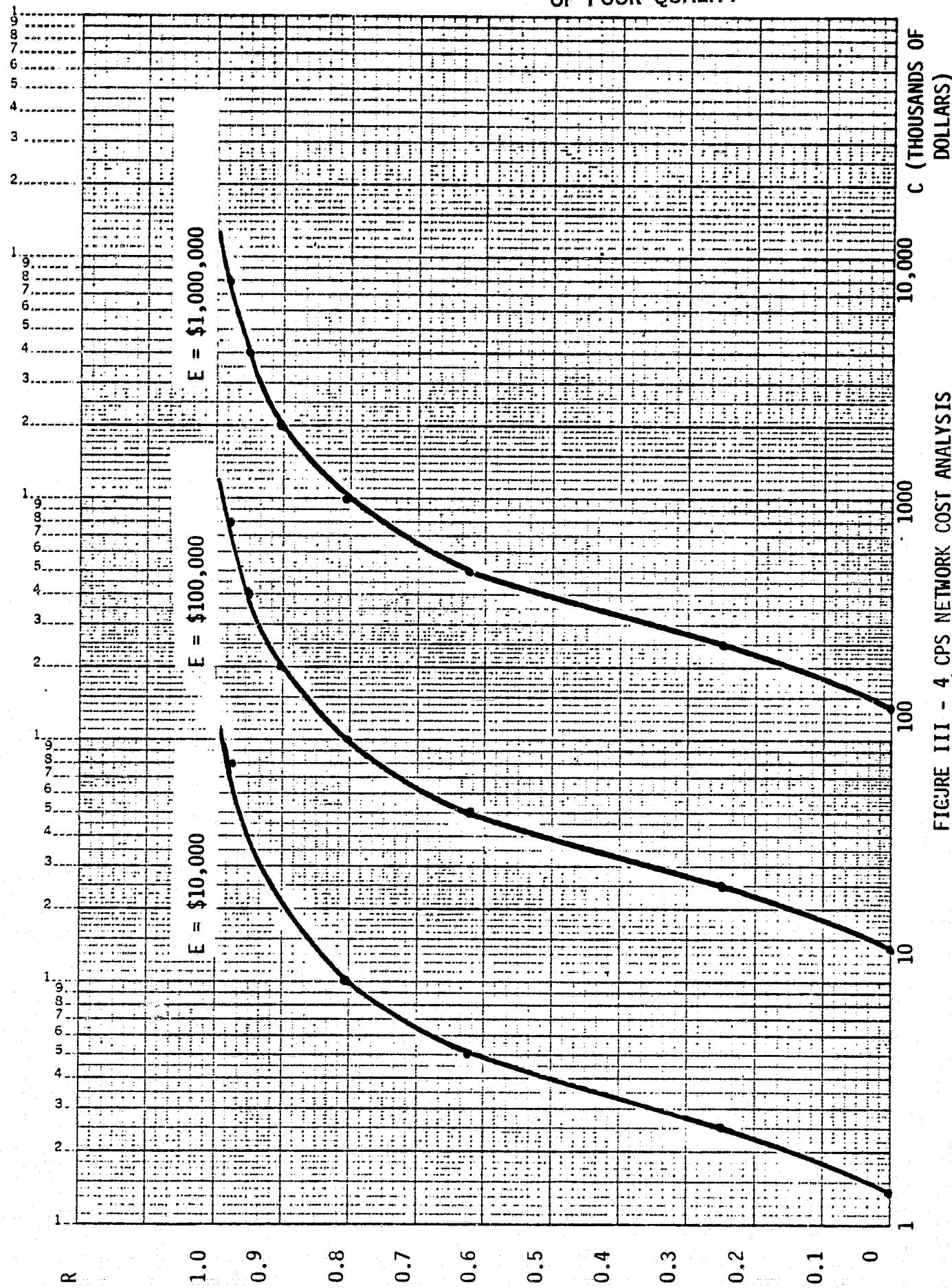


FIGURE III - 4. CPS NETWORK COST ANALYSIS

approach to satisfying their communications needs.

Users whose traffic requirements will not justify a CPS earth station at a particular location may be able to join with other users in their geographical vicinity to assemble enough traffic to install one.

This will expand the market for CPS networks by making them economical for organizations with many low traffic locations. The costs of the required terrestrial connections must of course be considered in determining the feasibility of such arrangements compared with using trunking service.

4.2 CONNECTIVITY REQUIREMENTS

Connectivity describes the communication links between users and ground stations, between ground stations and satellites, between and within satellites, transponders, and spot beams required to provide data, voice, and video services.

Connectivity requirements for each service are dependent upon traffic and performance requirements, service mode (CPS or trunking), and the necessary service availability. Connectivity is affected by the number of satellites and transponders per satellite, the number of spot beams, the required geographical distribution of service and the interconnection with terrestrial and other satellite systems. It, in turn, impacts on the technology required, e.g., multibeam, multi-hop, intersatellite links, etc.

Other issues which may be affected by connectivity requirements are:

1. Geographic distribution and location of satellites.
2. Deployment of satellites specialized by service, e.g. voice service.
3. Use of reliability improvement techniques, e.g. diversity and adaptive power techniques to improve fade margin.
4. Tradeoff between connectivity and performance requirements, e.g. connectivity vs. delay.

4.2.1 DATA SERVICE CONNECTIVITY

Connectivity requirements for data transmission vary widely among the different data communication applications. It is convenient to distinguish between those applications requiring dedicated service and those requiring switched service.

4.2.1.1 DEDICATED DATA TRAFFIC

A large portion of data traffic requires dedicated service on leased line (or privately owned) networks. These networks link the various remote locations of companies or governmental agencies, and while some need for dedicated intercompany connectivity exists, the more usual requirement is for connection between establishments of the same corporation or agency.

While many dedicated data communications links involve

the simple pre-assigned connection of two points, there are also frequent needs (for example, those associated with the polling of remote terminals from a central site) that require multipoint connections.

Dedicated traffic is suitable for transmission via either CPS or trunking configurations. However, CPS configurations in the Ka band are not likely to meet the availability requirements of most real-time data applications and should be reserved primarily for that portion of traffic using deferred or store-and-forward transmissions. An exclusively CPS configuration is practical for data transmission only when the establishments at both ends of the link are large enough to support on-site dedicated earth stations and where availability requirements are not severe. CPS to CPS transmission of this type are likely for applications such as electronic mail. For example, CPS earth stations co-located with large regional post offices may offer an excellent and cost effective means of providing the lower availability dedicated links suitable for the large volume expansion of mailgram-type services planned by the U.S. Postal System.

While a limited number of instances, such as the above, may be cited where CPS to CPS transmission modes provide a cost effective solution to special problems of data transmission connectivity, in the general case requirements will often exist for connec-

tions between two or more small organizations for which on-site earth stations are impractical. It is also necessary to provide for dedicated links between many small organizations (without CPS) and one or more large central locations which may have an on-site earth station (for example, the linking of remote sales offices to a computer system at corporate headquarters). It is therefore highly likely that trunking will be required (even for those establishments capable of supporting CPS earth stations) so that the smaller establishments may be addressed. As a result, the satellite system should provide the means for interconnection of dedicated links between establishments using CPS and trunking modes. This interconnection will most probably be achieved at common ground stations, thus reducing the complexity of the satellite communication subsystems.

Total Ka-band satellite traffic far exceeds the capacity of a single transponder. The multiple transponders within the satellite require means for connecting data users assigned to different transponders. This is relatively straightforward as long as all earth stations are addressable by the same satellite. If multiple satellites are used, either an intersatellite link or a ground station connection will be required, with resulting increased delay and system complexity.

The problem of reaching a station, whose antenna points at one satellite, from a station whose antenna points at a different satellite, requires some form of interconnectivity between satellites. Whether this is best established by intersatellite link, or via multiple relay through earth stations involves many complex tradeoffs between costs, flexibility, and the accumulation of time delays (which under some data communications protocols has adverse effects on throughput). Fortunately, for dedicated data service the problems of intersatellite connectivity are lessened by the fact that the origin and destination of channels are pre-assigned. Dedicated users can, with relative ease, be segregated into small communities of users all of whom can (under some system designs) be assigned to the same satellite. While some loss in the flexibility of reconfiguration may be implied, the separation of users into such communities provides an additional method of achieving desired connectivity assignments.

4.2.1.2 SWITCHED DATA TRAFFIC

Connectivity requirements for switched data traffic tend to be similar to, but more demanding than those for dedicated data traffic. Whereas dedicated traffic involves pre-assigned connectivity among limited communities of users, switched traffic involves on-demand connection to a potentially very large community of recipients.

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The same considerations relative to interconnection between CPS and trunking users discussed under Dedicated Data Traffic applies even more strongly for switched traffic. Because of the need to address a wide range of possible recipients, independent on the size of the establishment in which they reside, links between CPS and trunking modes are essential.

Polled operation, which might occasion the need for multipoint connectivity among data terminals, is not commonly encountered in switched circuits and therefore switched data traffic tends to be point-to-point (through the switches) rather than multipoint.

There are, however, needs for many-to-one switched data connections as in the case of terminals widely separated throughout a region individually calling in to a central computer (similar to In-WATS) and the reverse (e.g. a computer sequentially dialing remote terminals to accept their accumulated data as in Out-WATS). The essential connection, however, remains point-to-point and the many-to-one nature of these applications is primarily tariff oriented. For switched data traffic, connection to both long haul and local terrestrial facilities will be needed. While the satellite system may ultimately grow to a very large size, and be capable of reaching, through its own facilities, most or all of the significant population centers, it is likely to be a long term

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gradual growth. As result, the need to reach a wide range of potential addresses (which is inherent in switched network operation) will initially require routing through terrestrial facilities to cities not yet included in the satellite network. With this pattern of interoperability established at the beginning, it is likely to continue throughout the evolution and maturity of the satellite system.

The connectivity problems, imposed by the multi-beam and/or multisatellite environment expected in some of the high traffic scenarios, are potentially complex for switched data traffic. The need to reach a large number of widely dispersed users on demand requires sophistication in the ability to direct transmissions from beam-to-beam and from satellite-to-satellite without incurring undesirably long transmission delays.

The ability to solve multisatellite connectivity problems by assigning user communities to the same satellite is not a viable option in the case of switched data since wide distribution to all potential users is usually required.

4.2.2 VOICE SERVICE CONNECTIVITY

Connectivity requirements for voice traffic transmitted by Ka satellite depends upon the type of service provided. For the purpose of describing this connectivity, voice traffic will be divided according to

dedicated business, MTS business, and MTS residential voice services.

A voice service network used by a corporation usually contains a combination of dedicated facilities used to reach various corporate or customer locations having a high volume of traffic and MTS facilities used to reach other corporate and non-corporate locations and to provide emergency backup or overflow connections to the locations normally reached by the dedicated facilities. The interconnection between the dedicated and MTS facilities occurs in switching machines which are a part of the overall network. In these networks the dedicated and MTS connections to the switches are functionally distinct, although in the absence of CPS service they may use the same physical facilities. Physical separation of some or all of the dedicated facilities into CPS and non-CPS carried circuits thus presents no special problems.

4.2.2.1 DEDICATED TRAFFIC

The most commonly encountered leased line configurations are:

- (a) Lines connecting two establishments which have a high volume of dedicated traffic.
- (b) Intracompany networks connecting multiple locations.

(c) Foreign exchange lines connecting an establishment in one city with a central office in a remote city. These are usually used for non-toll customer access, for example, as for airline reservations.

Connectivity requirements for leased line voice traffic are similar to those of dedicated data traffic. That is, connectivity generally requires pre-assigned links between a limited number of locations. The required links are point-to-point only, because of the nature of voice transmission.

Dedicated links often carry switched traffic. For example, many intracompany dedicated networks terminate on PBX's which are used for local distribution within the customer's premises or for dial out to the surrounding local area. Another instance of this is the leasing of dedicated transmission facilities linking switches owned by a specialized common carrier. The SCC provides switched service to the customers served by its network nodes but may use dedicated lines obtained from another carrier (e.g. the Bell System) to provide the needed transmission facilities linking those nodes. As discussed with respect to dedicated data, the achievement of a desired connectivity may be complicated by the use of different spot beams, transponders, and multiple satellites, particularly in view of the requirement to hold delay to a

minimum. Fortunately in the case of dedicated voice traffic the fact that connectivity is pre-assigned and involves a limited number of locations, offers the possibility of solving these problems by grouping the user communities so that each community uses common satellite facilities.

4.2.2.2 MTS TRAFFIC

The general requirement of MTS traffic, whether business or residential, is the need to address a large number of possible recipients. Furthermore, this connectivity must be provided on demand rather than being pre-assigned. This is accomplished by the existing network through a hierarchy of switches and facilities.

Ka-band transmission can be used in two ways in the MTS network. Firstly, trunking routes can be set up between major centers (e.g., New York to Los Angeles) supplementing terrestrial and lower frequency satellite facilities. Such routes will require high availability and large capacity. Secondly, a CPS type network, using earth stations located directly on class 2, 3, or 4 switching centers can be used to directly connect locations with large common interest (e.g., Downtown New York City to Downtown Washington, D. C.). In this case the alternate routing capability of the network can be used to reroute calls if an outage occurs. (With the common channel interoffice

signalling system expected to be in widespread use by 1990, it would be possible to reroute calls in progress if necessary.)

4.2.3 BROADCAST TV

This service category includes Network TV and CATV, both of which have multipoint connectivity requirements from a limited number of origination points to a multiplicity of receive points. As described in Section II-5.2.3, only limited area networks are feasible using Ka band, and only if the overall cost is low enough for the service to tolerate short outages.

The use of spot beams, multiple transponders, or multiple satellites in various network configurations is not likely to impose important problems for either limited area Network TV or CATV. The limited number of up-links means that each originating site can look at each of several satellites without imposing inordinate increases in overall system costs. The receive-only locations need to look at only the most convenient satellite broadcasting the desired program material.

It is also possible to use multi-hop satellite transmissions to improve connectivity for Broadcast TV. This may be of particular importance in a multisatellite environment where not all earth stations look at each satellite. The one-way nature of the Broadcast TV transmissions eliminates concern over the addition-

al time delays introduced. The only disadvantages appear to be the possible accumulation of transmission impairments and some loss of spectrum efficiency because of the multiple transmissions of the same program.

4.2.4 SPECIAL PURPOSE VIDEO

Special purpose video may be one way or interactive. One way video such as that used in newsgathering and special events, usually requires full bandwidth. For interactive video, such as videoconferencing, narrower bandwidth, limited motion capabilities are generally acceptable.

Although videoconferencing via dedicated intracompany networks may be satisfactorily served via CPS stations, trunking becomes important as videoconferencing expands toward more frequent use of ad-hoc conferences between organizations at least one of which is not equipped with a CPS station.

Delay caused by interconnecting videoconferencing users via multiple satellite hops may be objectionable in videoconferencing because of the two way interactive nature of these conferences. This may limit the usefulness of multi-hop and intersatellite links in this application. Trunking modes of Interactive video require connectivity between transponders, beams, and satellites to which the trunks are connected. Interconnections between transponders and beams in the same

satellite cause small delay effects. However, multi-hop and intersatellite connections are subject to the same delay restrictions as imposed on the CPS mode.

4.2.5 CONNECTIVITY REQUIREMENT SUMMARY

The connectivity requirements for Ka band service categories are summarized in Figure III - 5. Note that the delay limitation category bears on the applicability of connectivity solution via multiple-hop and intersatellite links. It may be concluded from this summary that:

- CPS/Trunking connectivity is often needed.
- Satellite/Terrestrial connectivity is usually needed.
- Multiple-Hop and Intersatellite link delays are to be avoided when possible.

4.3 SATELLITE CAPACITY AND DISTRIBUTION REQUIREMENTS FOR TYPICAL WESTERN UNION NETWORK TOPOLOGIES

Typical topologies for a Western Union network may be visualized by examining the growth of the minimum specialized network discussed in Section 4.1. The minimum specialized network has been estimated to cover about 30% of the total accessible market, which represents the minimum viable coverage. (This minimum portion of the market must be served to attract a sufficient number of customers and subsequent traffic load.) Based upon the estimates made in Section II - 5.3.5, this minimum network could well be

SUMMARY OF CONNECTIVITY REQUIREMENTS

SERVICE	APPLICATION	CONNECTIVITY		USER CONNECTIVITY	DELAY LIMITATIONS ¹	CPS/TRUNKING INTERCONNECTIVITY		SATELLITE/TERRESTRIAL INTERCONNECTIVITY
		PRE-ASSIGNED POINT-TO-POINT AND MULTIPPOINT	ON-DEMAND POINT-TO-POINT			MILD	MEDIUM	
DATA	SWITCHED	WIDESPREAD	MILD	MILD	MILD	USUALLY NEEDED	USUALLY NEEDED	SOMETIMES NEEDED
VOICE	DEDICATED	PRE-ASSIGNED POINT-TO-POINT; OCCASIONAL CONFERENCE	LIMITED	MILD	MAJOR	OFTEN NEEDED	SOMETIMES NEEDED	SOMETIMES NEEDED
	MTS BUSINESS	ON-DEMAND POINT-TO-POINT; PLUS OCCASIONAL CONFERENCE	WIDESPREAD	MILD	MAJOR	USUALLY NEEDED	USUALLY NEEDED	USUALLY NEEDED
	MTS RESIDENTIAL	ON-DEMAND POINT-TO-POINT	WIDESPREAD	MILD	MAJOR	NOT APPLICABLE	USUALLY NEEDED	USUALLY NEEDED
BROADCAST	TV	PRE-ASSIGNED ONE-WAY BROADCAST (LIMITED AREA COVERAGE)	LIMITED	MILD	NONE	SOMETIMES NEEDED	OFTEN NEEDED	OFTEN NEEDED
VIDEO	SPECIAL	PRE-ASSIGNED ONE-WAY BROADCAST, WITH OR WITHOUT MIRRORBOARD RETURN CHANNEL	LIMITED	MILD	MINOR	SOMETIMES NEEDED	SOMETIMES NEEDED	SOMETIMES NEEDED
		PRE-ASSIGNED (EVOLVING TO ONE- WAY) TWO-WAY POINT-TO-POINT OR MULTIPPOINT VIDEOCONFERENCE	LIMITED/ WIDESPREAD	MAJOR	OFTEN/USUALLY NEEDED	OFTEN/USUALLY NEEDED	OFTEN/USUALLY NEEDED	OFTEN/USUALLY NEEDED

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FIGURE III-5

served by one satellite for each specialized carrier. (Separate satellites will probably be employed because of the range of variation possible in synchronization techniques, beam scan patterns, channel assignment algorithms, etc.)

The distribution requirements for traffic division among four separate satellites (one for each specialized carrier) are based upon the connectivity requirements given in Section 4.2 for the type of services offered by each specialized carrier. For example, MTS voice traffic, which requires maximum connectivity with all other users of the network, should be assigned a major portion of each satellite capacity, distributed by transponders and spot beams to provide maximum interconnectivity (as described in Section 4.2).

The specialized common network size grows from the minimum to meet additional traffic growth toward a predicted maximum specialized network size of 99 earth stations in the year 2000 (assuming that Ka-band service can be offered at 40% less than Ka-band service). On this basis, it was shown that the cumulative portion of this market captured by Ka-band in the year 2000 is 83.75%, based upon the total market value of the principal SMSA plus all of its subordinates located within a 50+ mile radius for hubbing.

If the market predictions are accurate for the year 2000, each specialized common carrier will have either

two or three satellites, depending upon their capture of the total market, the mixture of traffic, transponder capacity for trunking and CPS, etc. The additional connectivity requirements imposed by multiple satellites (see Section 4.2) impose constraints on the services provided (due to additional delay caused by multiple-hop or intersatellite links).

Since low earth station elevation angles result in higher attenuation due to rain (because of longer path length), satellite locations resulting in higher elevation angles will be sought and used, where available. If not available to both satellites of a specialized common carrier, the one providing a higher elevation angle will be dedicated to the services requiring increased reliability. The other satellite may be used for services which are tolerant of outages (usually deferred traffic). Distribution of satellite capacity, by services, among several satellites for each specialized common carrier will therefore probably depend upon service reliability needs, based upon geographical distribution of rainfall throughout CONUS and the satellite elevation angle.

Interconnectivity between satellites of different carriers, e.g., MTS traffic from one carrier to another, requires appropriate links and standards. These intercarrier links may be located at earth stations or as part of a terrestrial network. Standards will be required to interface differences in synchronization, protocols, etc. between carriers.

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1. 30/20 GHz Net Accessible Market Assessment, Western Union Report No. CR-159837, February, 1980.
2. 18/30 GHz Fixed Service Communications Satellite System Study, Hughes Aircraft Company, Report No. 159627, September, 1979.
3. 30/20 GHz Mixed User Architecture Development Study, TRW Inc., Report No. NASA CR-159686, October, 1979.
4. 18/30 GHz Fixed Communications System Service Demand Assessment, Western Union Report No. CR-159547 Vol. II, July, 1979.
5. Propagation Effects Handbook for Satellite Systems Design, A Summary of Propagation Impairments on 10-100 GHz Satellite Links, with Techniques for System Design. ORI TR 1679, NASA Communications Division, NASA Headquarters, Washington, D.C., March, 1980.

IV

PROPAGATION EFFECTS ON THE TRANSMISSION PATH

1.0 STATEMENT OF THE PROBLEM

The requirements of this subtask are to identify 30/20 GHz propagation characteristics, and provide a basis for establishing expected effects on typical links used in support of candidate services.

2.0 INTRODUCTION

Rain attenuation on the transmission path, and the resulting large link margin requirements required to provide high availability performance, is the most significant factor in identifying the services that can be accommodated by 30/20 GHz satellite communication systems. This section presents the key precipitation data that will be compared to the availability and performance requirements of the trunking and CPS services developed in Section II. The resulting link margin requirements establish the Ka-band system parameters necessary to satisfy service availability/performance criteria and to identify system limitations.

3.0 METHODOLOGY

The most recent NASA handbook on propagation effects at 30/20 GHz and other sources were used to develop the required propagation information.

Using the propagation statistics, fade depths and link margin requirements were computed for each of the CONUS

rain zones identified. Pertinent fade duration statistics, rain attenuation characteristics as a function of earth station elevation angle, and space diversity gain data from the referenced publications were used to derive the data presented.

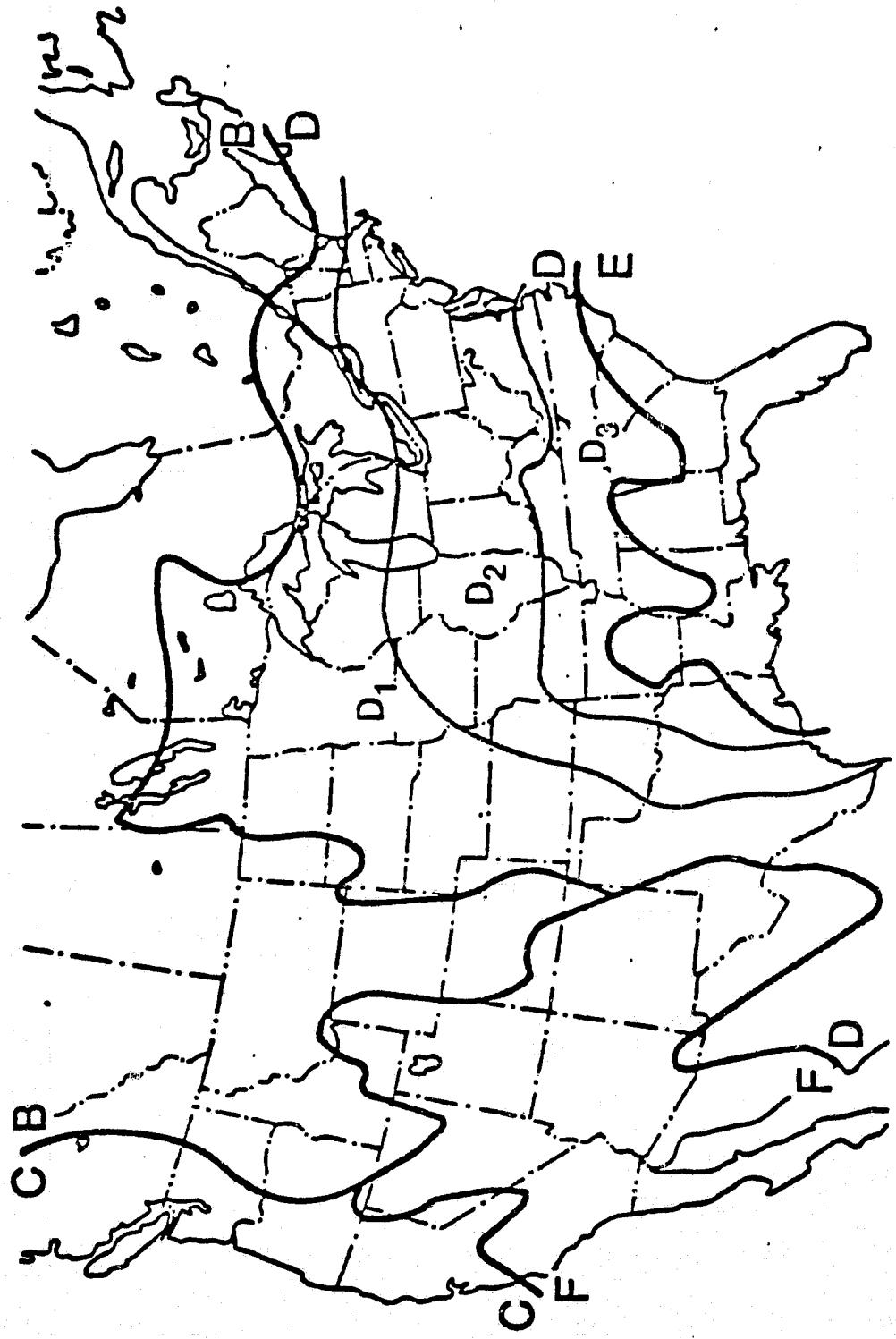
4.0 PROPAGATION CHARACTERISTICS

Figure IV-1 shows the rain rate climate regions for the continental United States (CONUS). Figure IV-2 shows the point rain rate distributions as a function of the CONUS rain regions. Region D is subdivided into three subzones and the rain rate distribution for each of the subzones is shown in Figure IV-2(b). Using the procedures from the NASA Handbook and the point rain rate statistics in Figure IV-2, fade depths as a function of percent of time the fade depth is exceeded were computed for each of the rain zones. To maintain a given level of link availability, the precipitation margin required equals the rain fade depth; thus the data computed is identified as Precipitation Margins for the 20 GHz and 30 GHz Links in Tables IV-1 and IV-2, respectively.

The data has been computed for each rain zone at the appropriate elevation angle, since rain attenuation varies appreciably with earth station elevation angle, particularly in high rain rate regions. Figure IV-3 shows rain attenuation characteristics as a function of earth station elevation angle.

The satellite location can be optimized to provide the

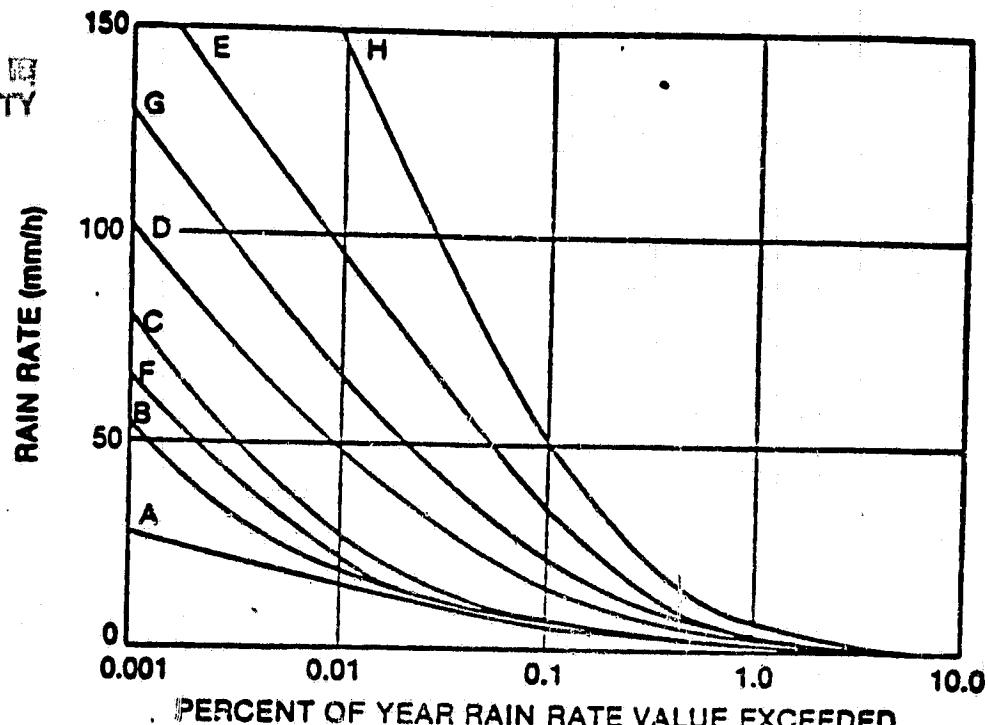
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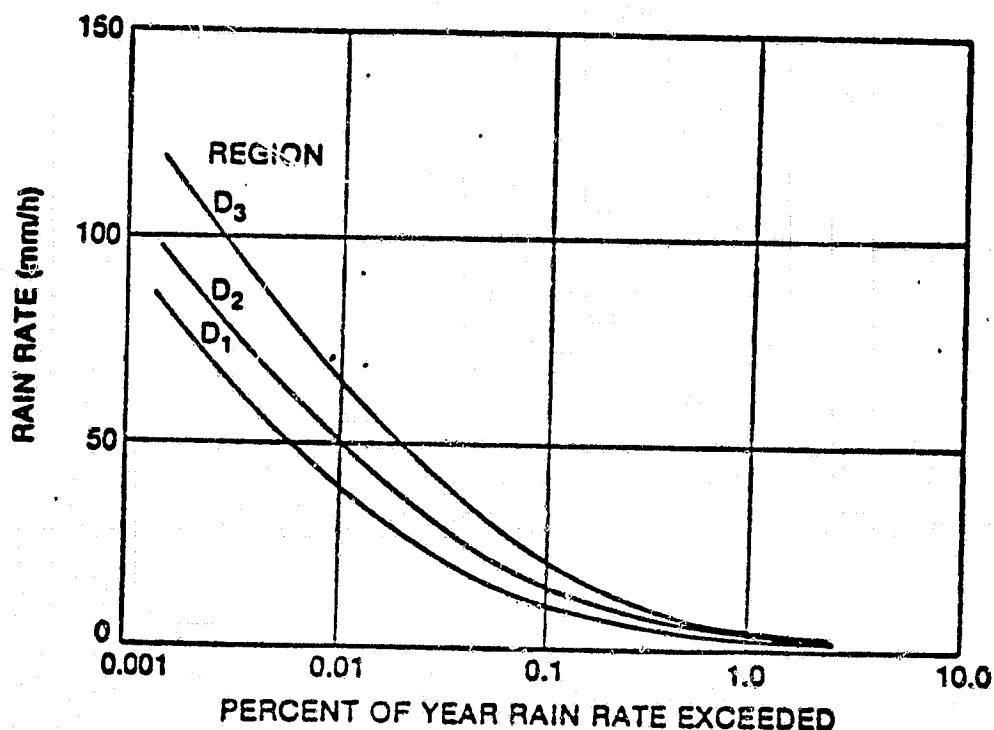
RAIN RATE CLIMATE REGIONS FOR THE
CONTINENTAL UNITED STATES SHOWING
THE SUBDIVISION OF REGION D

FIGURE IV - 1

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(a) Climate Regions A to H



(b) Climate Regions D divided into three subregions
(D₂ = D above)

POINT RAIN RATE DISTRIBUTIONS AS A
FUNCTION OF PERCENT OF YEAR EXCEEDED

FIGURE IV - 2

Rain Attenuation in dB for Satellite at 90°W

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(20 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	13	6	4	1	1
C	30	20	8	5	1	1
D ₁	40	23	9	6	2	1
D ₂	45	28	12	8	3	1
D ₃	50	36	17	12	3	2
E	55	55	29	20	4	2
F	40	17	6	4	2	1

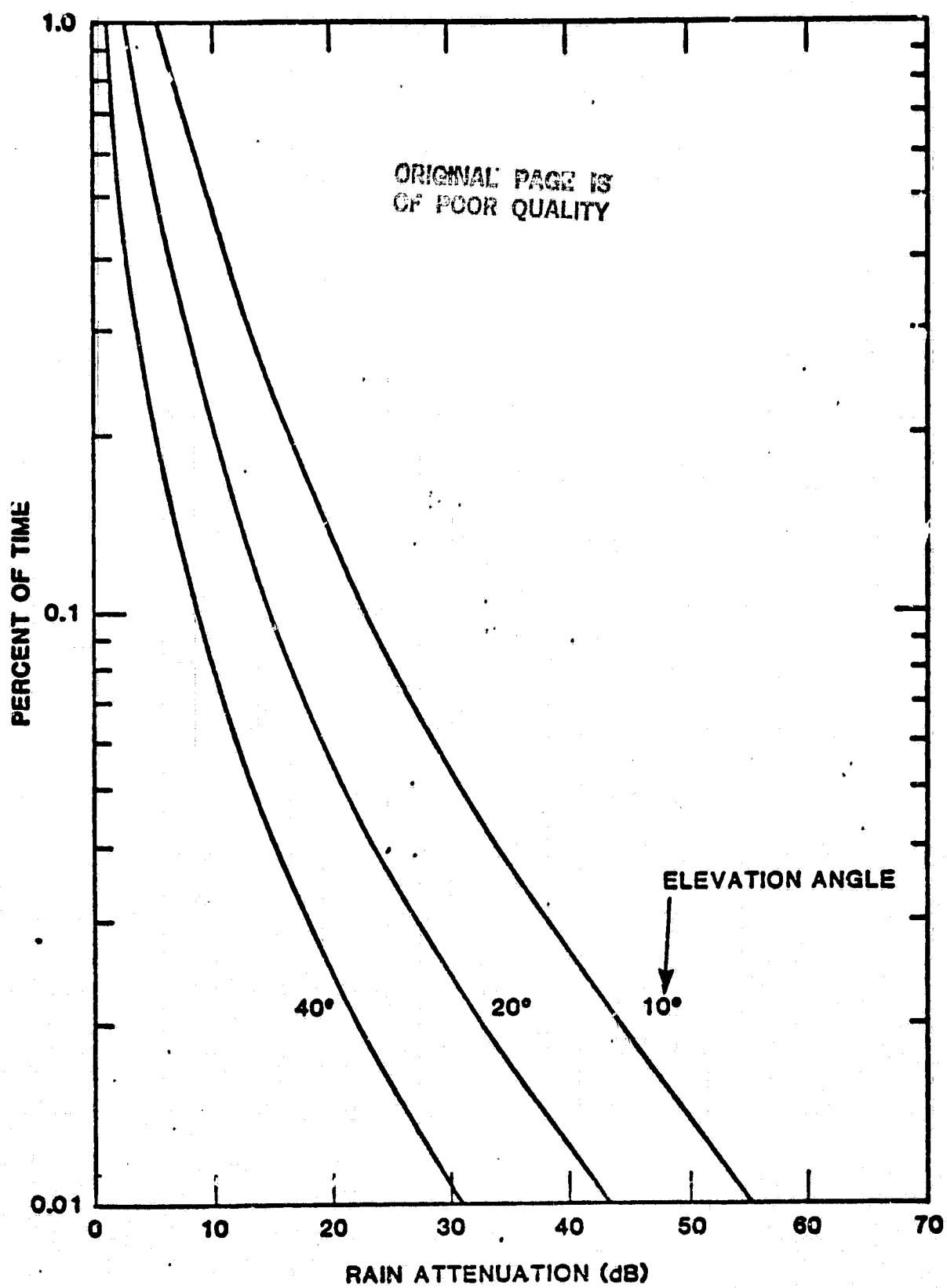
TABLE IV - 1

Rain Attenuation in dB for Satellite at 90°W

(30 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	13	9	3	2
C	30	45	17	11	3	2
D ₁	40	50	21	14	4	2
D ₂	45	63	28	18	6	3
D ₃	50	80	39	27	8	4
E	55	120	64	43	10	4
F	40	37	13	9	4	2

TABLE IV - 2



VARIATION OF RAIN ATTENUATION OF A FUNCTION OF ELEVATION ANGLE-ZONE D₂

FIGURE IV - 3

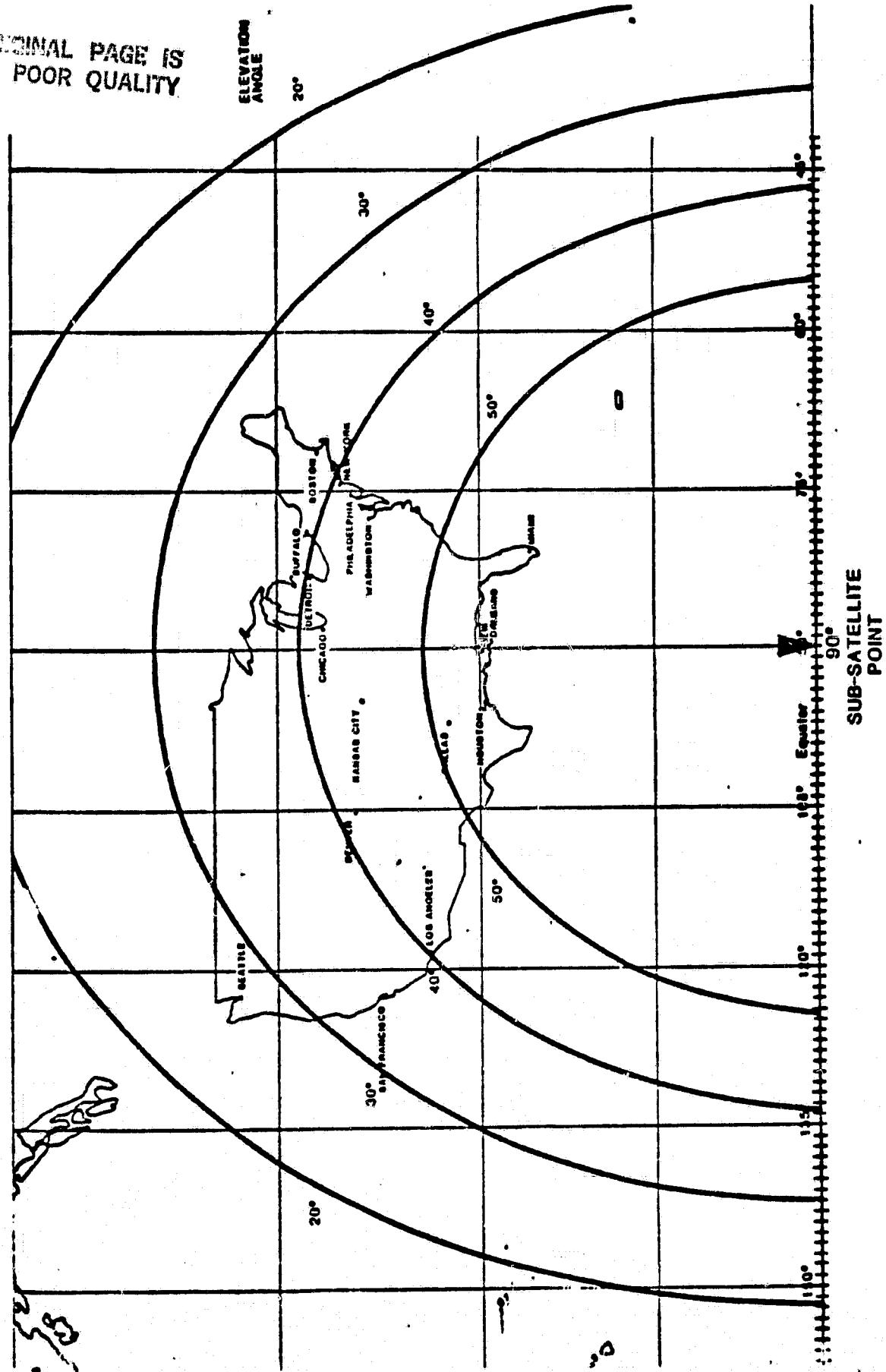
best weighted CONUS coverage with the lowest margin requirements. Figure IV-4 and IV-5 show the elevation angle contours superimposed on the CONUS for satellite locations at 90°W and 97°W longitude, respectively. The optimum location is at 97°W. At orbital arc locations below 90°W and above 104°W appreciable performance degradation in major population centers will be experienced.

Of particular interest is the relationship between total annual rain attenuation and the worst month attenuation. Figure IV-6 shows the results of rain attenuation measurements, as a ratio of worst month to total annual attenuation, recorded at Greenbelt, MD. The worst month attenuation exceeded the average annual level by factors of 5 to 7.5.

Figures IV-7 to IV-9 show fade duration distributions at three widely separated locations: Holmdel(NJ), Slough (England), and Rosman (NC) respectively. Fade durations and the number of fades vary among the three because the measurement period and the elevation look angle (and consequently the rain path length) were different at the three sites. The distribution characteristics at the three sites are, however, similar.

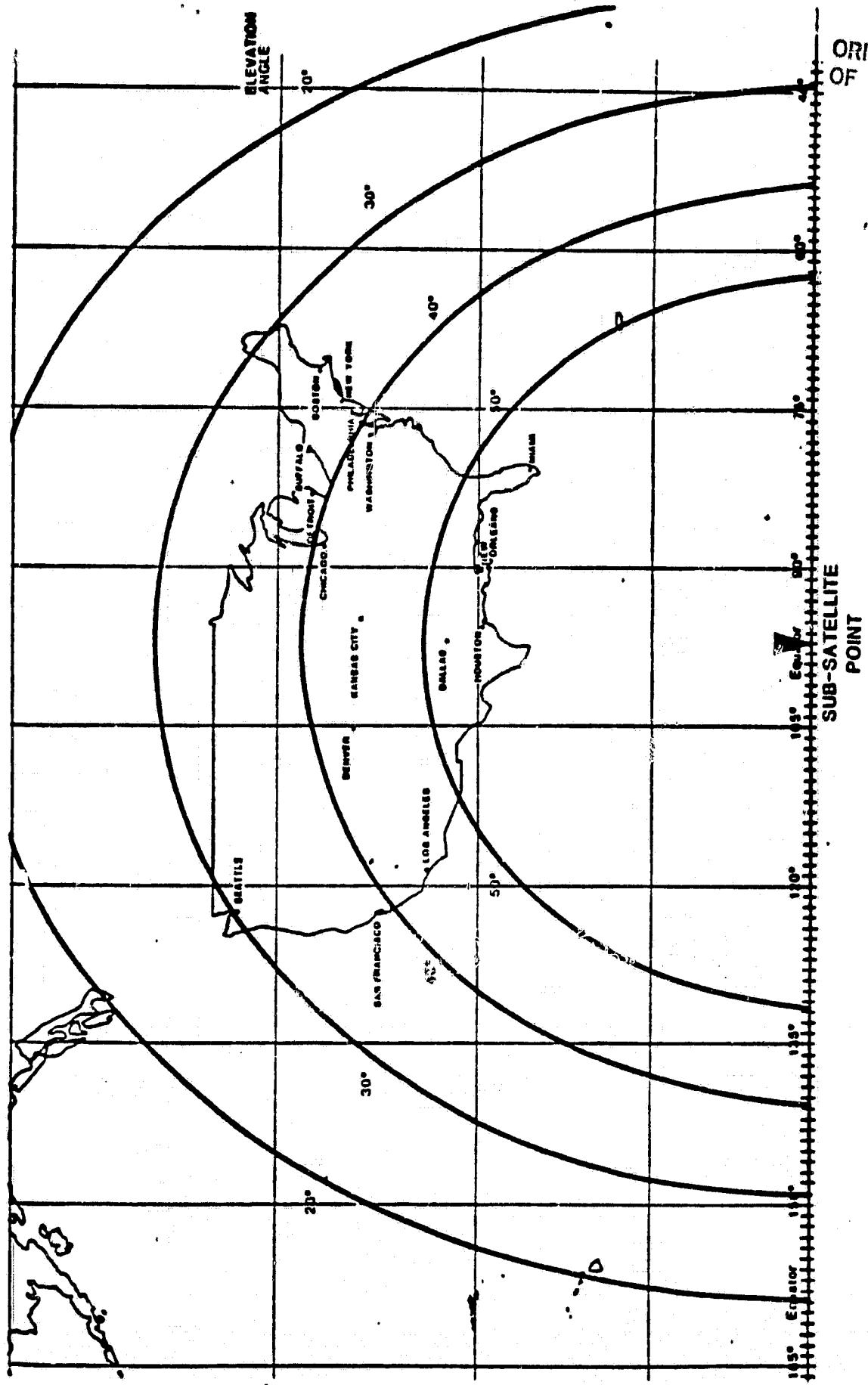
Figure IV-10 is a histogram showing the percentage of each month the three fade depths indicated were exceeded. The data is the result of measurements made at

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SATELLITE AT 90° W LONGITUDE

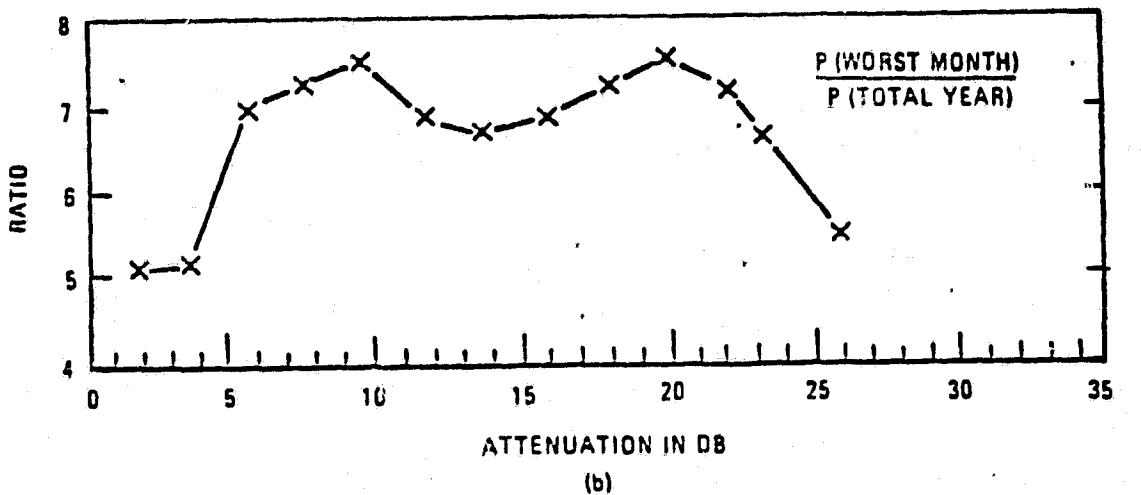
FIGURE IV - 4



SATELLITE AT 97°W LONGITUDE

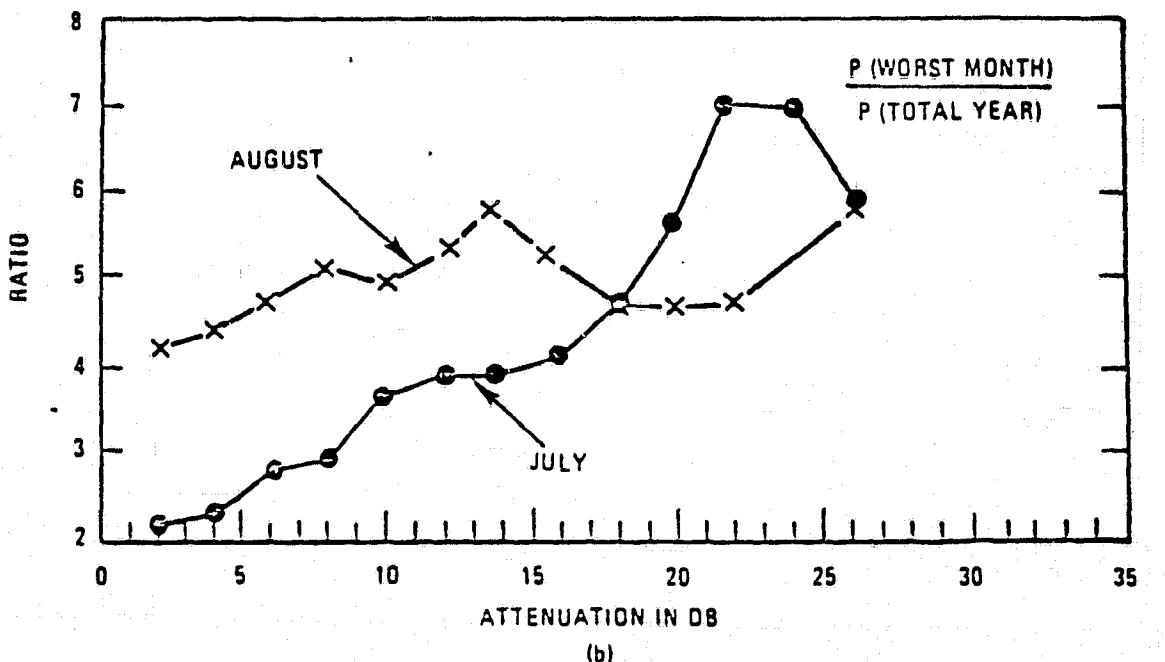
FIGURE IV - 5

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(b)

Figure 4-13. Comparison of Worst Month and Annual Attenuation Statistics for 1977.



(b)

Figure 4-14. 11.76 GHz Attenuation Distributions, Greenbelt, Maryland

FIGURE IV - 6

C-2

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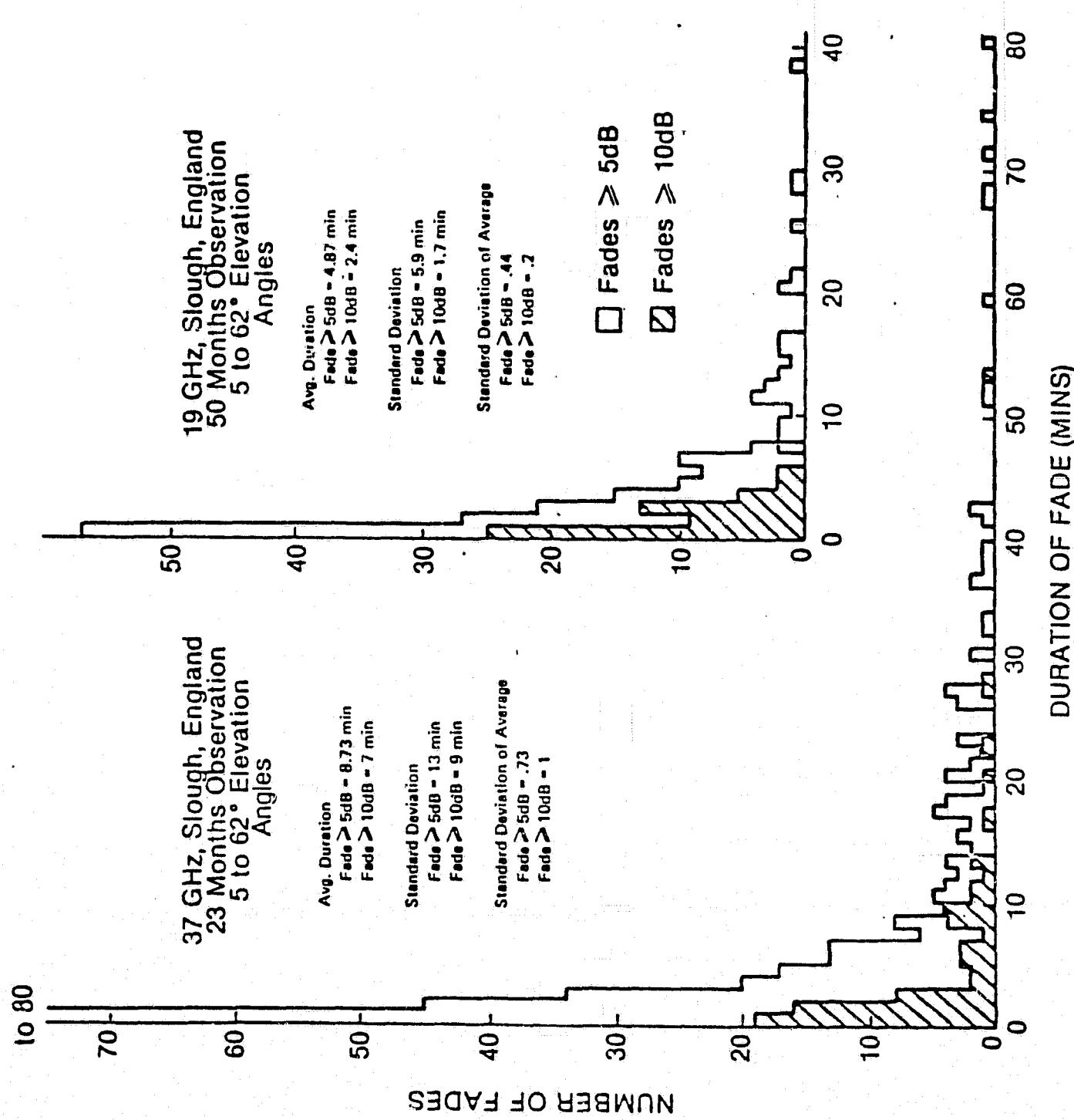
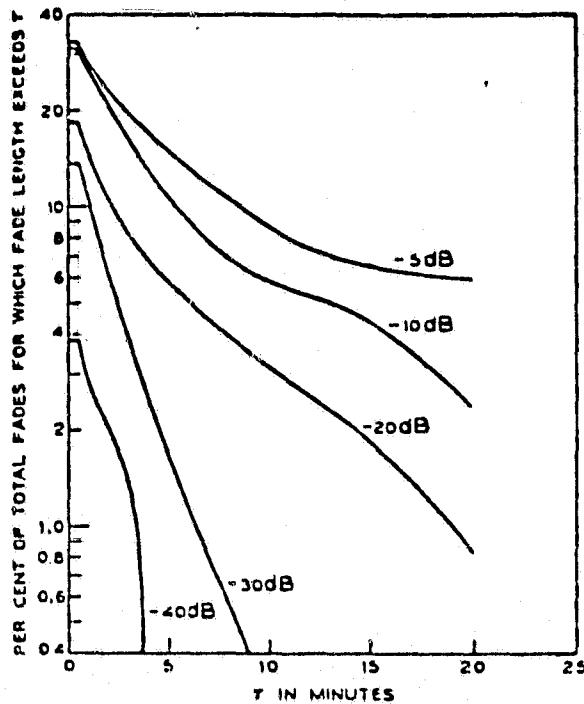


FIGURE IV - 7

HISTOGRAMS OF FADES GREATER THAN
5 AND 10 dB AT 19 AND 37 GHz

Source: Reference 1

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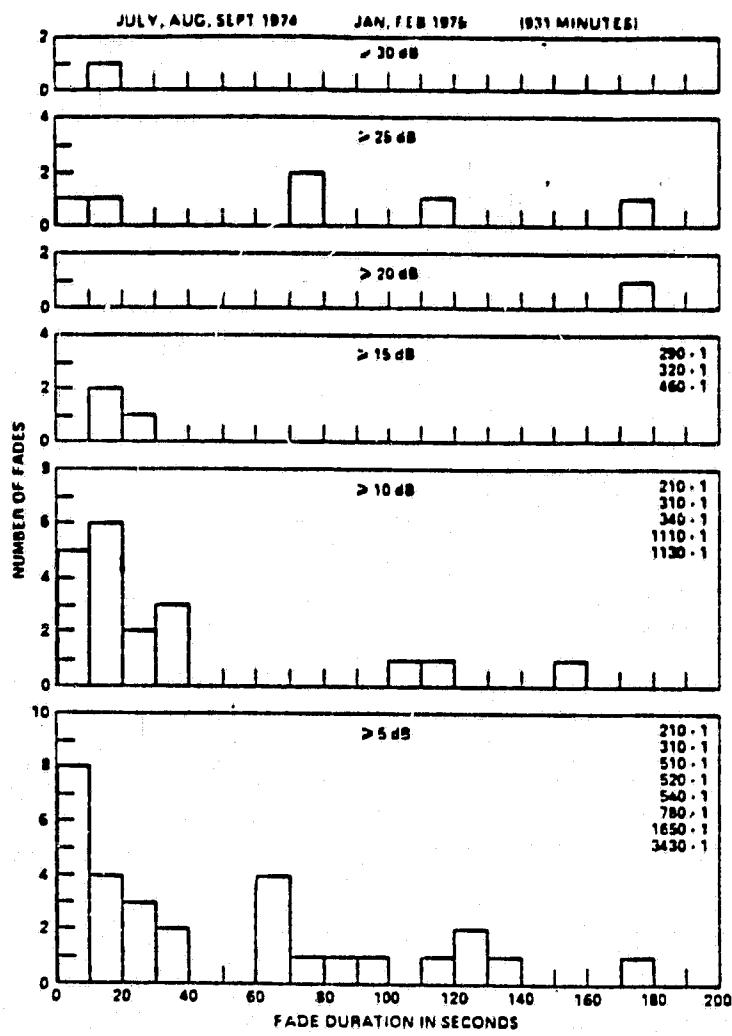


HOLMDEL, N. J.

PERCENT OF TOTAL NUMBER OF FADES FOR
WHICH THE FADE LENGTH EXCEEDS THE ABSCISSA.
BASED ON 178 HOURS OF RAIN DATA AND A TOTAL
OF 182 FADES.

FIGURE IV - 8

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FADE DURATION HISTOGRAM FOR
30 GHz AT ROSMAN, NORTH CAROLINA

FIGURE IV - 9

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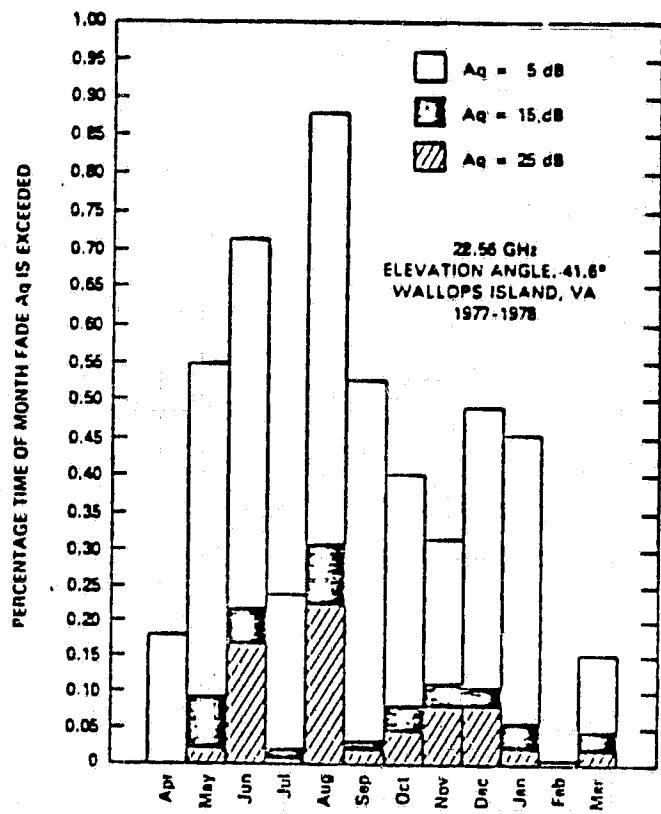


Figure 5.5-1. Histogram denoting percentage times for various months the fades of 5, 15, and 25 dB were exceeded.

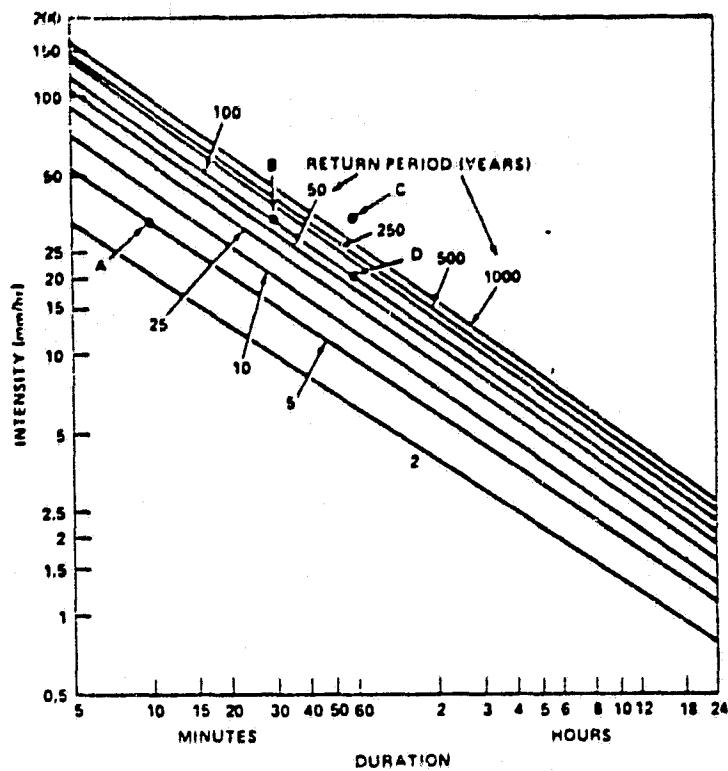
FIGURE IV - 10

Wallop Island, VA illustrating typical fade distribution characteristics by month. Monthly distribution varies considerably between sites as can be seen by comparing Figures IV-6 and IV-10, two sites that are approximately 150 miles apart. At Greenbelt the worst month is July whereas August is the worst month at Walllops Island. Additional data for Richland, WA is shown in Figure IV-11 to illustrate variances between sites. Fade duration statistics are useful in estimating blocking probabilities for message switched services on occasions during which adaptive FEC is activated to accommodate severe fading, or other means are used to exchange available bandwidth for performance quality on remaining circuits.

Figure IV-12 shows that fade characteristics are relatively independent of frequency. A reasonably accurate estimate of rain attenuation can therefore be made from data at a single spot frequency.

5.0 SPACE DIVERSITY

Space diversity has been used for a number of years in terrestrial microwave systems. In such systems it is generally used to combat degradations due to ducting, multipath, and other phenomena characteristic of paths near and parallel to the earth's surface. The use of space (or "separation") diversity with satellite links is primarily intended to combat high attenuation due to intense precipitation. The basis for use of a diversity



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Figure 6. Average total precipitation, Richland, Washington, area.

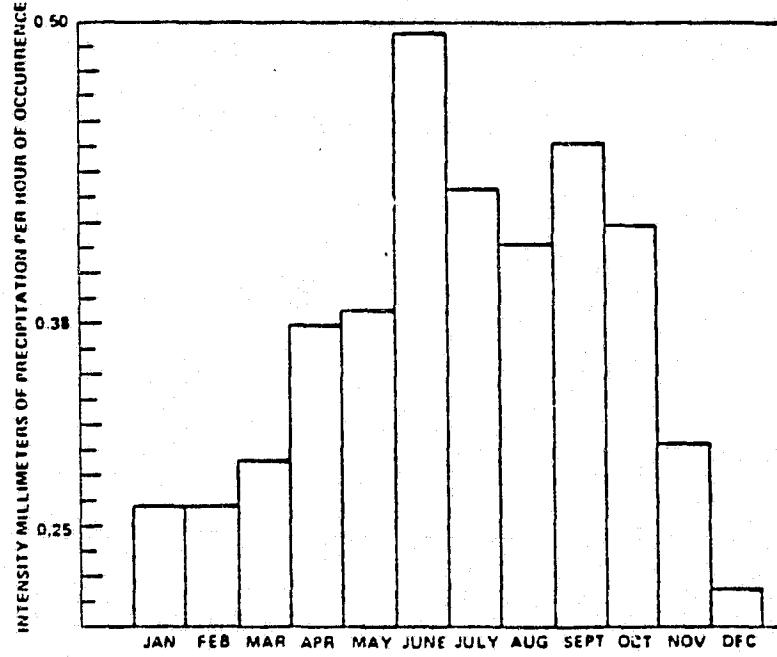
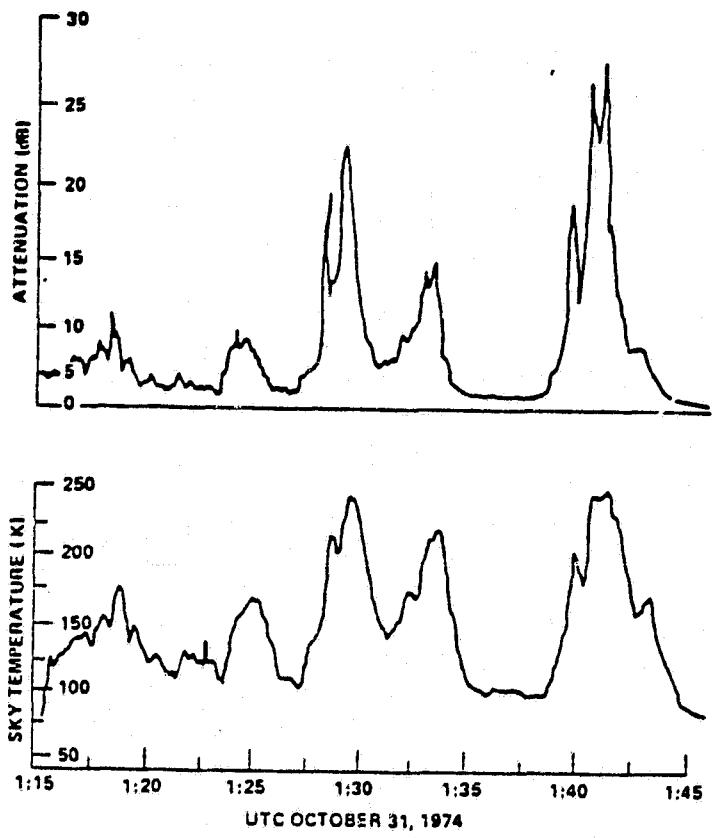


Figure 7. Average monthly precipitation intensity factors based on the period from 1946-1970.

FIGURE IV - 11

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30-GHz ATTENUATION AND
20-GHz SKY TEMPERATURE

FIGURE IV - 12

system is the observation that regions of intense rainfall are generally limited in geographic extent. This is true for temperate climates. The physical separation of the satellite earth stations then serves to reduce the correlation of such heavy rainfall at the sites. Some simple means of choosing the better of the sites at any instant then completes the diversity system.

A useful tool in the study of diversity systems is the concept of "diversity gain," as developed by D. Hodge of Ohio State University. The derivation of diversity gain is best illustrated by a figure. In Figure IV-13 the two curves to the right are the individual cumulative time distributions of attenuation for the two sites operating individually. The single curve to the left is the cumulative time distribution for diversity operation--that is, the better of the two stations at any instant. As shown, the distance between the curves for the same percentage time is the diversity gain in decibels.

Hodge has determined an empirical relationship between the separation distance, fade depth, and diversity gain based on measurements made using ATS-V. These measurements were taken at 15.3 GHz. This relation is as follows:

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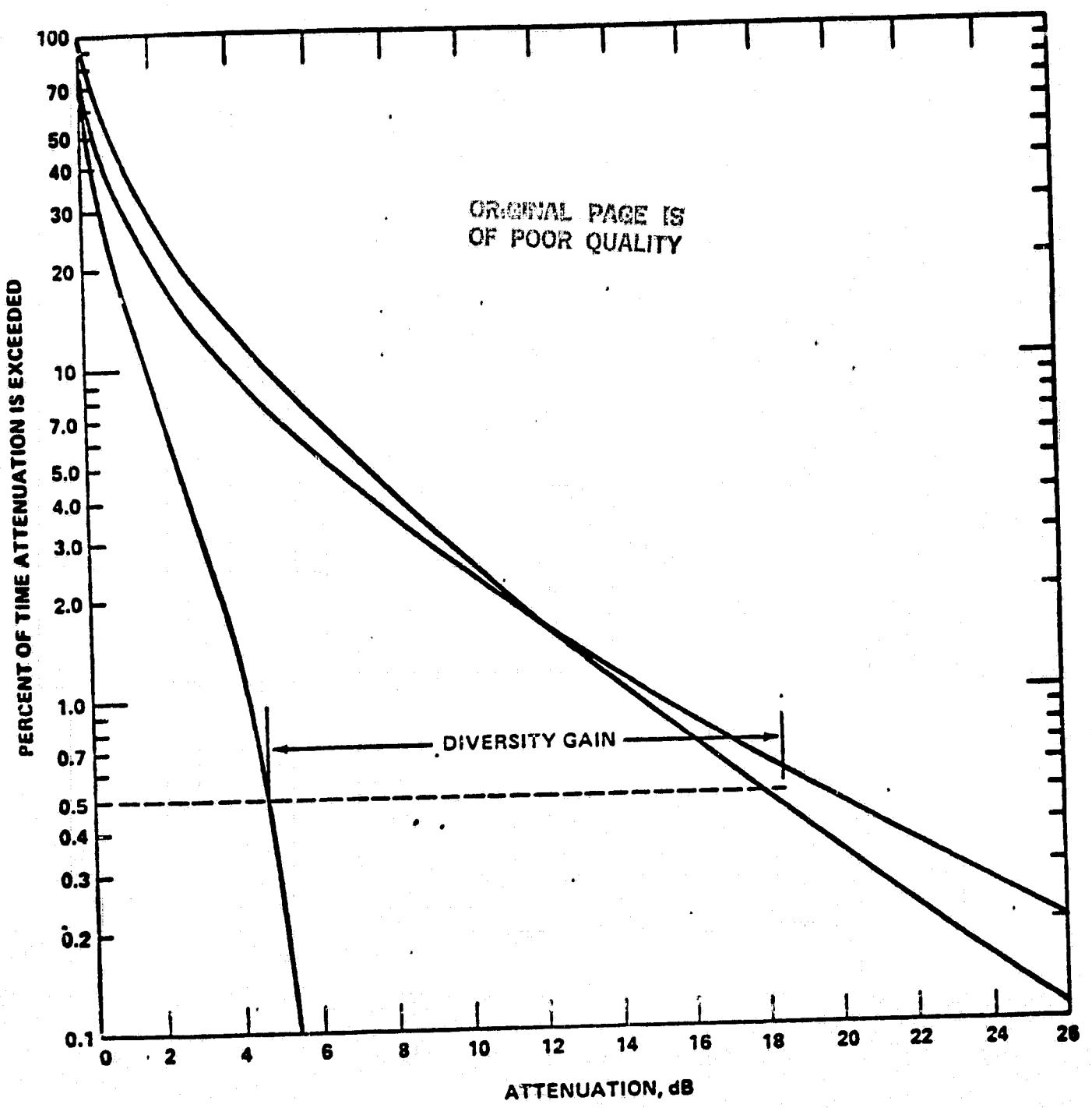


FIGURE IV-13.
DIVERSITY GAIN CALCULATION

$$G = a(1 - \exp(-bD))$$

where

G = Diversity gain in dB

D = The site separation distance in km

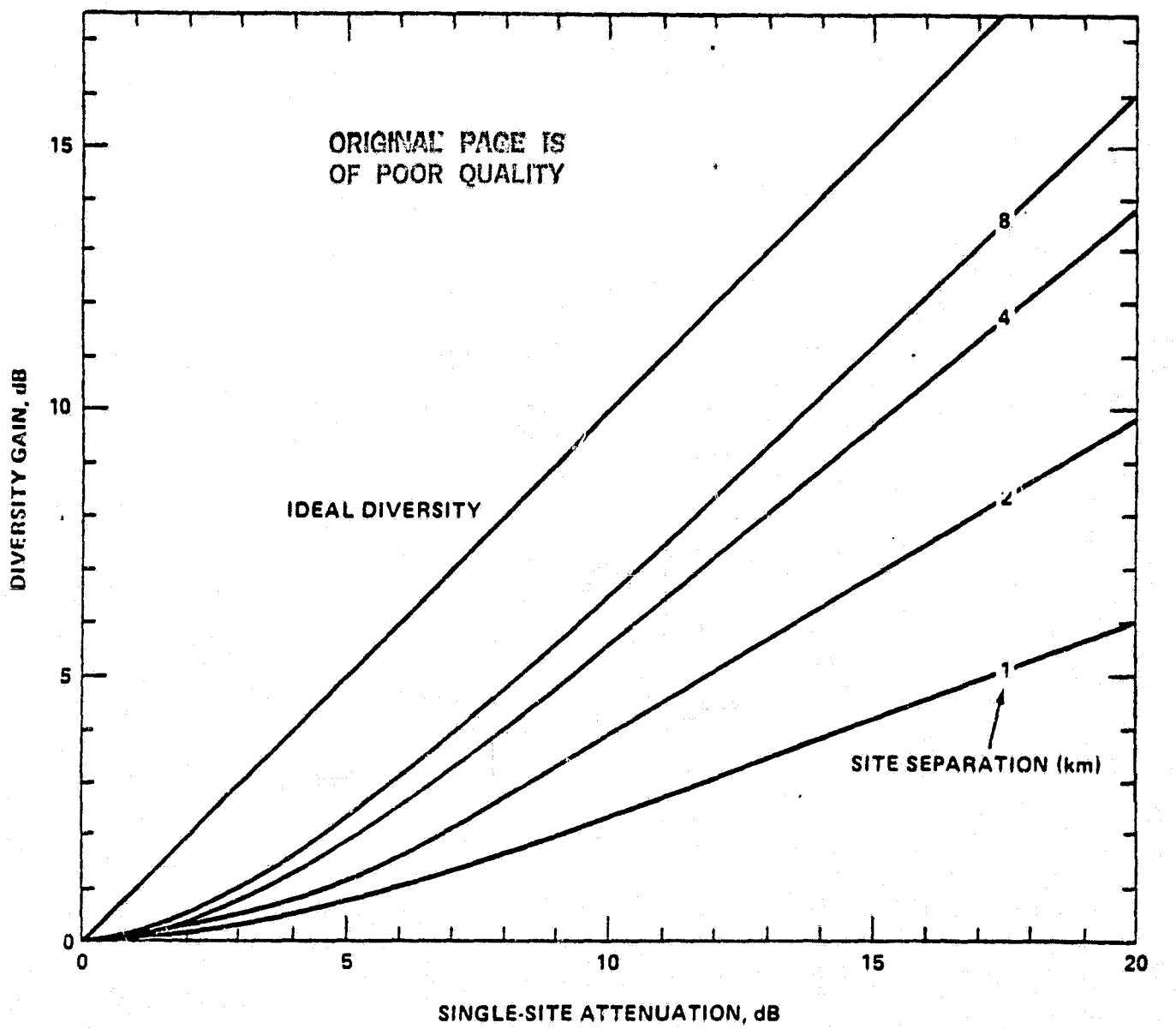
a = $A - 3.6(1 - \exp(-0.24A))$

A = The single site attenuation in dB

b = $0.46(1 - \exp(-2.26A))$

Data taken using ATS-6 indicated that the diversity gain was not strongly dependent on frequency. A satisfactory separation for the diversity sites seems to be about 8 to 10 km. Diversity gain as a function of separation is shown in Figure IV-14.

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DIVERSITY GAIN FOR VARIOUS SEPARATIONS
(Hodge, 1976)

FIGURE IV - 14

TRANSMISSION SYSTEM CONSIDERATIONS

1.0 GENERAL CONSIDERATIONS

In Section II an analysis of the net accessible Ka-band market was made to estimate the portion of that market that might actually be captured by Ka band communications systems and the share of the estimated traffic volume that might be captured by the individual satellite carriers in their respective market areas. The transmission requirements of the carrier community may be divided into three separately identifiable systems in accordance with the services provided. The three system categories are: trunking, CPS, and combined trunking/CPS. A trunking system being appropriate for Bell, combined trunking/CPS for carriers such as Western Union and RCA, and all CPS for carriers addressing those market areas of interest to SBS, XTEN, SPC, etc. Each of these system categories requires a different satellite system design.

From the work in Section II the Western Union market areas require both Trunking and CPS satellite system capabilities. The projected Western Union market share is estimated to grow to 7.5 GBPS in each category by the year 2000. An estimate of the size of an initial satellite in terms of capacity was identified previously at 4 GBPS of trunking capacity and 2 GBPS of CPS capacity. In the Phase I - Task 9 effort the

marginal utility of adding one more earth station in the trunking network was that the traffic capacity of that earth station be at least .11% of the total projected trunking traffic. For a two carrier split of the total traffic the minimum capacity required is .22% or 33 MBPS. The maximum network size for Ka services priced 20% below Ku band service is 89 earth stations. On the assumption that the objective of the two dominant private-carriers is to implement at least the most efficient network size (34 earth stations each), the minimum traffic capacity at any earth station is at least 30 MBPS. On this basis a SS-TDMA trunking system operating at a 500 MBPS burst rate is a reasonable choice. Ultimately 15 transponders at 500 MBPS each will be required to accommodate the projected traffic.

In the CPS case the traffic volume is the aggregate of a large number of small networks that include corporate, institutional, government, and low capacity trunking networks. Assuming that ultimately CPS services will be carried through some 1000 earth stations the average transmission capacity per station is 7.5 MBPS. Some will be as low as 64 KBPS, others may be in the 20-30 MBPS range or possibly higher. The nominal 32/128 MBPS uplink and 250 MBPS downlink transmission rates are reasonable choices for CPS, however, it will probably be more desirable to customize at least the

uplink transmission--and in the case of the southeastern region the downlink transmission--to provide adequate system margins (normal operating margin plus margin obtained by adaptive measures) to meet availability requirements. This is discussed further in Subsection 4.2.

In the following subsections some specific systems consideration are discussed in some detail.

2.0 PERFORMANCE

The two key measures of performance are BER and availability. The required BER performance, 1×10^{-7} , is driven by data transmission requirements. (Typically in PCM encoded voice and video systems BER performance levels of 1×10^{-6} and 1×10^{-5} respectively will provide high quality service.) The transmission link analysis is based on the 1×10^{-7} BER.

Availability requirements have been discussed in Section II. In the trunking transmission network, a link availability objective of .9999 has been established. To meet the availability objective both adaptive compensation and diversity earth stations are generally necessary. However, as discussed in Section II, this availability could be obtained by considering use of terrestrial and other satellite bands.

The availability objective for the CPS services is .9990 although .9950 would be an acceptable level for some types of traffic. The availability criteria for

each user network would be considered individually to avoid an overdesign, although the basic system (satellite/earth station) design requirements are specified to meet the .9990 availability objective.

3.0 RAIN ATTENUATION COMPENSATION

The severity of rain attenuation in the 30/20 GHz band, particularly where high system availability is required, mandates that the system designer consider multiple techniques for improving system availability. These would include adaptive power control, adaptive FEC, space diversity earth station complexes, and location of the satellite within the domestic orbital arc. Any or all of these techniques would be appropriate in a given system.

3.1 ADAPTIVE POWER CONTROL

To meet availability objectives both the trunking and CPS systems require use of adaptive power control. In the trunking case adaptive power control is required for both the uplink and downlink. In the CPS case the satellite transmitter is operated normally at maximum output power and adaptive power control is limited to the uplink. Subsection 4.0 provides link summaries giving normal operating and adaptive power levels necessary for the trunking and CPS systems.

3.2 FORWARD ERROR CONTROL

The use of FEC is necessary in the CPS systems but need not be included in the trunking system. FEC has

the advantage of providing large increases in bit error performance and margin to offset the effects of rain attenuation. Rate 1/2 encoding with soft decision decoding, which will provide an 8.8dB coding gain at a constant transmission rate, has been assumed as a standard. However, the use of that rate does not imply that the total information data rate of the CPS system will be reduced to half of the uncoded transmission data rate. FEC is specified to be applied to individual sites that are under the influence of rain attenuation at the port rate within the Terrestrial Interface Modules and not at the transmission burst rate. The probability that more than 10% of the network stations are experiencing such conditions simultaneously is quite low. Thus for a station network with uniform distribution of traffic, (i.e. each has a peak hour traffic of 2.5 MBPS), one station out of ten experiencing rain conditions will reduce total throughput capacity from 250 MBPS to 225 MBPS. The impact on system throughput and blocking probability in the case of voice circuits even at peak hours will be relatively low as long as capacity can be reassigned among the stations. In off-peak hours there is not likely to be any noticeable effect on network transmission.

There are a number of interesting control scenarios by which required bandwidth can be allocated to stations

experiencing fades. These should be investigated to devise an optimum algorithm for resource control.

3.3 SPACE DIVERSITY EARTH STATIONS

To meet a postulated .9999 availability requirement for a trunking system, implementation of space diversity earth stations is required at all trunking nodes. A description of the diversity gain/spacing characteristics was given in Section IV. Diversity experiments are essential, since empirical data to substantiate the belief that there is a dB for dB diversity gain improvement for cases where single site attenuation exceeds the 15-18 dB range is not available. The importance of space diversity gain improvements is paramount to meeting trunking network availability objectives, since if the expected diversity gain improvements cannot be obtained, Ka band systems would not be an acceptable medium for trunking transmission under the .9999 availability assumption. However, as noted above, many trunking networks could tolerate poorer availability with appropriate network design and "fail-soft" operating procedures, so that this assumption requires further study.

3.4 SATELLITE POSITION IN THE DOMESTIC ORBITAL ARC

Rain attenuation increases appreciably as earth station elevation angles decrease. In Section IV the variation of rain attenuation as a function of elevation angle was given together with a plot of elevation

angle contours in CONUS. By selection of the satellite location in the orbital arc the best weighted CONUS coverage with the lowest rain margins can be obtained. From the plots in Section IV the optimum satellite position is 97° W longitude, providing a minimum elevation angle in CONUS of 30°. For orbital arc locations below 90°W and above 104° W the increased attenuation due to lower elevation angles in major population centers becomes a critical factor. The useful orbital arc can be extended through use of intersatellite links (to be discussed separately).

3.5 ADDITIONAL CONSIDERATIONS

Additional system margin can be obtained by adaptive reduction of the transmission data rate, providing an increased level of energy per bit for given available transmitter power conditions. The approach should be examined but is not considered a preferred choice because of its impact on throughput capacity and channel blocking. In subsection 4.0 reduced transmission data rates are considered to meet availability requirements for CPS stations in CONUS rain zone E, but in that case the peak transmission requirements would be considered in the design and the necessary total capacity provided through use of an appropriate number of FDM channels.

To minimize reduction in throughput data rates an adaptive reduction in the number of quantization bits

for digital voice channels can be employed. For example if the eight bit code normally used for voice channel quantization is reduced to six bits the per channel data rate is reduced from 64KBPS to 48KBPS. This approach should be explored as part of system design trade-off consideration.

4.0 EARTH STATION ANTENNA SIZE AND SYSTEM MARGIN CONSIDERATIONS

4.1 TRUNKING STATIONS

Both Hughes and TRW, in the baseline and alternative designs submitted to date, advocate use of large (12 meter) antennas for trunking systems. Western Union expects that a 5 meter antenna will be adequate for the trunking system, and in any event would not consider an antenna larger than 7 meters as being cost-effective. To substantiate the position that a 5 meter antenna will satisfy trunking network requirements comparative data is presented below using 5, 7, and 12 meter antennas.

There are a number of reasons why a 12 meter antenna is not a desirable choice. A 12 meter antenna is large, and with the surface tolerance requirements (.01 inch RMS or better) for the Ka band it is unlikely that a vendor would quote on providing the antenna on other than a developmental basis. The antenna cost will be very high. The beamwidth of the 12 meter

antenna is very narrow (.058°) and the foundation and structural rigidity required to meet operational performance requirements at wind velocities up to 60 MPH, (and slightly reduced performance in gusts up to 80 MPH) is severe and costly. (The degradation or tracking error at an average wind velocity of 35 MPH was not specified by Hughes or TRW.) There is no reason why the environmental requirements for the Ka-band antenna should be relaxed relative to "C" or "Ku" band systems. Environmental performance requirements normally specified by WU are given in Appendix A. The 12 meter antenna will also require a tracking subsystem somewhat more sophisticated and expensive than a step-track system. Further, since diversity systems will in any case be required at trunking nodes (see below), system cost is substantially increased because two 12 meter antennas per site are required.

The beamwidth of a 5.0M antenna is .14°, simplifying tracking requirements to that which may be accommodated with a step-track system. Surface tolerances are more easily obtained because of the smaller size, and foundation/structural rigidity requirements can be met at a lower cost because of the smaller surface area.

Tables V-1 through V-3 give uncoded link budgets for 12, 7, and 5 meter trunking systems, respectively. Using the earth station and satellite transmitter power levels shown the available margins for rain loss

**CASE 1 - 12.0 ES Antenna
Trunking TDMA 500 Mbps Link Budget**
(Clear Weather)

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
ORIGINAL PAGE IS OF POOR QUALITY			
TRANSMITTER POWER	21.6 (150 W)	10 (10W)	dBW
TX. ANTENNA GAIN	69.0 (12 M)	51.2	dB
POINTING LOSS	2.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	86.6	59.2	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	50.4	65.0	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	1.4	1.5	dB
NOISE TEMPERATURE @ LNA INPUT	29.0	28.7	dB . K
BOLTZMANN'S K	220.6	228.6	dBW/Hz/K
C/I/KT (NOT INCLUDING RAIN FADE)	120.6	110.6	dB . Hz
INFO. BIT RATE	87.0	87.0	dB . Hz
CHANNEL E_b/N_0 (EFFECTIVE SYSTEM)	33.6	23.2	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
E_b/N_0 REQUIRED	10.6	10.6	dB
RAIN LOSS MARGIN	20.0	9.6	dB

**Case 2 - 7.0 ES Antenna
Trunking TDMA 500 Mbps Link Budget^a**

(Clear Weather)

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	21.6 (150 W)	10 (low)	dBW
TX. ANTENNA GAIN	64.2	51.2	dB
POINTING LOSS	1.5	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	82.3	58.2	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	50.4	60.3	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	1.4	1.5	dB
NOISE TEMPERATURE @ LNA INPUT	29.0	28.7	dB . K
BOLTZMANN'S K	220.6	228.6	dBW/Hz/K
C/kt (NOT INCLUDING RAIN FADE)	116.3	105.9	dB . Hz
INFO. BIT RATE	87.0	87.0	dB . Hz
CHANNEL E_b/N_0 (EFFECTIVE SYSTEM)	29.3	18.9	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
E_b/N_0 REQUIRED	10.6	10.6	dB
RAIN LOSS MARGIN	15.7	5.3	dB

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TABLE V -- 2

Case 3 - 5.0 ES Antenna
Trunking TDMA 500 Mbps Link Budget
(Clear Weather)

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
ORIGINAL PAGE IS OF POOR QUALITY			
TRANSMITTER POWER	21.6 (150 W)	10	dBW
TX. ANTENNA GAIN	61.2	51.2	dBi
POINTING LOSS	1.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	79.8	50.2	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	60.4	57.4	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	1.4	1.5	dB
NOISE TEMPERATURE @ LNA INPUT	29.0	20.7	dB . K
BOLTZMANN'S K	220.6	226.6	dBW/Hz/K
C/kt (NOT INCLUDING RAIN FADE)	113.8	103.0	dB . Hz
INFO. BIT RATE	87.0	87.0	dB . Hz
CHANNEL E_b/N_0 (EFFECTIVE SYSTEM)	26.8	16.0	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
E_b/N_0 REQUIRED	10.6	10.6	dB
RAIN LOSS MARGIN	13.2	2.4	dB

TABLE V - 3

are as shown. In Table V-4, and the similar tables, the required margins that can be accommodated by a 5 meter system are identified by diagonal lines. The additional cases that can be accommodated by 7 meter and 12 meter systems are indicated by the circles and triangles, respectively. The 12 meter case includes all 7 and 5 meter cases and the 7 meter case includes all 5 meter cases. The results indicate that the 7 and 12 meter systems have somewhat better clear weather margin than the 5 meter system. If we now add adaptive power control in the uplinks and downlinks the following total margins are obtained.

NORMAL OPERATING PLUS ADAPTIVE POWER MARGIN

Antenna size (M)	Up-link pwr. inc.	Down-link pwr. inc.	Total Margin (dB)	
			DB	U.L. D.L.
12.0	4.9	8.75	24.9	18.35
7.0	4.9	8.75	20.2	13.65
5.0	4.9	8.75	17.3	10.75

Table V-5 shows the availability levels in each rain zone that can be attained using combined normal operating plus adaptive power margins. Consider now the effects of adding rate 1/2 FEC margin (8.8dB) to the previous margins. Table V-6 shows the availability levels in each rain zone that can be attained with a combination of normal operation, adaptive power, and/-

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Table V-4
Trunking System Availability
Normal Operating Margin Only
Rain Attenuation in dB for Satellite at 90°W
(20 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	13	6	4	x	x
C	30	20	8	5	x	x
D ₁	40	23	9	6	x	x
D ₂	45	23	12	8	③	x
D ₃	50	36	17	22	③	x
E	55	55	29	20	④	x
F	40	17	6	4	x	x

Rain Attenuation in dB for Satellite at 90°W
(30 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	13	8	x	x
C	30	45	17	x	x	x
D ₁	40	50	21	14	x	x
D ₂	45	63	28	18	x	x
D ₃	50	80	39	27	x	x
E	55	120	64	43	10	x
F	40	37	13	8	x	x

KEY: / 5.0 M system 0 7.0 M system

△ 12.0 M system

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Table V-5
Trunking System Availability with
Normal Operating & Adaptive PWR Margin
Rain Attenuation in dB for Satellite at 90°W
(20 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded	0.01	0.05	0.1	0.5	1.0
B	35		13		x	x	x
C	30		20		x	x	x
D ₁	40		23		x	x	x
D ₂	45		28	12	x	x	x
D ₃	50		36	17	12	x	x
E	55		55	29	20	x	x
F	40		17	8	x	x	x

Rain Attenuation in dB for Satellite at 90°W
(30 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded	0.01	0.05	0.1	0.5	1.0
B	35		29	15	x	x	x
C	30		45	17	21	x	x
D ₁	40		50	21	14	x	x
D ₂	45		63	28	18	x	x
D ₃	50		80	39	27	x	x
E	55		120	64	43	x	x
F	40		37	15	8	x	x

KEY: / 5.0 M system

○ 7.0 M system

△ 12.0 M system

Adaptive Power Level Increase

UL 4.9 dB

DL 8.75 dB

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Table V-6
Trunking System availability with
Normal Operating, Adaptive PWR & FEC Margins
Rain Attenuation in dB for Satellite at 90°W
(20 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	15	8	X	X	X
C	30	20	8	X	X	X
D ₁	40	23	8	X	X	X
D ₂	45	28	12	X	X	X
D ₃	50	36	17	X	X	X
E	55	55	29	29	X	X
F	40	X	8	X	X	X

Rain Attenuation in dB for Satellite at 90°W
(30 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	15	8	X	X
C	30	45	17	X	X	X
D ₁	40	50	21	X	X	X
D ₂	45	63	28	18	8	X
D ₃	50	80	39	27	8	X
E	55	120	64	43	18	X
F	40	37	15	8	X	X

KEY: / 5.0 M system

FEC Gain 8.8 dB

O 7.0 M system

△ 12.0 M system

or adaptive FEC margins for the three antenna sizes.

From Table V-6 it is seen that an availability of .9999 is not realized by any of the three antenna sizes.

If instead of FEC we consider the use of space diversity earth stations at the trunking nodes, a diversity gain of 12 dB can be realized for the case where the single site attenuation is 18.0 dB. The combined margin available, i.e., operating margin plus adaptive power plus diversity gain is:

COMBINED MARGIN

Antenna size (M)	UL (dB)	DL (dB)
12.0	36.9	30.35
7.0	32.2	25.65
5.0	29.3	22.75

Table V-7 shows the availability levels that can be attained in each rain zone with a combined margin made up of normal operating margin, adaptive power margin, and diversity gain at a fade depth to 18 dB.

From Table V-7 the 12 meter system will provide an availability of .9995 in one additional rain zone and an availability of .9999 in two additional rain zones over the 5 meter system on the downlink. There is no advantage to the 12 meter system over the 5 meter systems for the uplink.

In both cases a .9999 availability requirement for CONUS has not been met.

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Table V-7
 Trunking System Availability with
 Normal Operating Margin, Adaptive PWR & Diversity
 Gain Margins
Rain Attenuation in dB for Satellite at 90°W
 (20 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	15	8	X	X	X
C	30	20	8	5	X	X
D ₁	40	23	8	8	X	X
D ₂	45	28	12	8	3	X
D ₃	50	36	11	12	3	X
E	55	55	29	20	X	X
F	40	17	8	X	X	X

Rain Attenuation in dB for Satellite at 90°W
 (30 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	18	8	3	X
C	30	45	21	11	3	X
D ₁	40	50	21	15	X	X
D ₂	45	63	28	18	3	X
D ₃	50	80	39	21	3	X
E	55	120	64	43	18	X
F	40	37	18	8	X	X

KEY: / 5.0 M system

△ 7.0 M system
 ▲ 12.0 M system

Diversity Gain 12 db for 18 dB
 Single Site Atten.

dB/dB above 18 dB

If the diversity gain increases dB for dB for single site attenuations greater than 18dB then a .9999 availability requirement will be met by all three antenna sizes.

The conclusion is that a 5 meter earth station with use of normal operating margins plus adaptive power control and space diversity will satisfy trunking system performance requirements, and larger antennas are not warranted.

4.2 CPS STATIONS

Table V-8 gives a link budget for a CPS TDMA system at 32 MBPS uplink and 256 MBPS downlink burst rates. The available clear weather margin for the uplink is 10.7 dB, and for the downlink, 5.3 dB. The crossed out cases in Table V-9 show that on the downlink the clear-weather margin provides an availability of .995 in all rain zones and .999 in rain zones B, C, and F. An uplink availability of .995 is provided in all but rain zones E and D₃.

With the margin increase due to adaptive FEC (8.8dB), the total uplink and downlink margins are 19.5 and 14.1 dB, respectively. The availability on the downlink is then .999 in all rain zones except rain zone E and on the uplink is then .999 in all rain zones zone except D₃ and E (circled cases).

The use of uplink adaptive power control to increase the ES power amplifier output from 11.7 to 19.2 dBw

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Table V-8
CPS TDMA 32 Mbps Link Budget
(Clear Weather, No Coding)

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	11.7 (15W)	18.7 (75W)	dBW
TX. ANTENNA GAIN	50.1	40.6	dB
POINTING LOSS	1.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	66.8	64.3	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	52.7	52.6	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	2.0	2.6	dB
NOISE TEMPERATURE AT RCVR INPUT	32.2	29.6	dB · K
BOLTZMANN'S K	220.6	220.6	dBW/Hz/K
C/I/KT	99.3	102.9	dB · Hz
INFO. BIT RATE	75.0	34.0	dB · Hz
CHANNEL E_b/N_0	24.3	18.9	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
E_b/N_0 REQUIRED	10.6	10.6	dB
CLEAR WEATHER MARGIN	10.7	5.3	dB

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Table V-9
**CPS System Availability with normal
Operating Margin, Adaptive UL PWR, Adaptive FEC**
Rain Attenuation in dB for Satellite at 90°W
(20 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded	0.01	0.05	0.1	0.5	1.0
B	35	13		6	X	X	X
C	30	20		8	X	X	X
D ₁	40	23		9	6	X	X
D ₂	45	28		12	8	X	X
D ₃	50	36		17	12	X	X
E	55	55		29	20	X	X
F	40	17		6	X	X	X

Rain Attenuation in dB for Satellite at 90°W
(30 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded	0.01	0.05	0.1	0.5	1.0
B	35	29		13	9	X	X
C	30	45		17	11	X	X
D ₁	40	50		21	14	X	X
D ₂	45	63		28	18	X	X
D ₃	50	80		39	27	8	X
E	55	120		64	43	10	X
F	40	37		13	9	X	X

KEY: / Normal Operating Margin

Margins
 PWR 14.5 dB
 FEC 8.8 dB

Q Adaptive FEC-UL & DL
 ▲ Adaptive UL PWR

Table V-10

CPS TDMA 128 Mbps Link Budget
(Clear Weather, No Coding)

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	11.7 (15W)	10.7 (75W)	dBW
TX. ANTENNA GAIN	58.1	48.6	dB
POINTING LOSS	1.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	66.8	54.3	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	52.7	52.6	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	2.0	2.0	dB
NOISE TEMPERATURE AT RCVR INPUT	32.2	29.6	dB · K
BOLTZMANN'S K	228.6	228.6	dBW/Hz/K
C/I/T	99.3	102.9	dB · Hz
INFO. BIT RATE	31.0	34.0	dB · Hz
CHANNEL E_b/N_0	18.3	18.9	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
E_b/N_0 REQUIRED	10.6	10.6	dB
CLEAR WEATHER MARGIN	4.7	5.3	dB

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Table V-11

CPS System Availability with Normal
Operating Margin, Adaptive FEC, Adaptive UL PWR
ORIGINAL PAGE IS Rain Attenuation in dB for Satellite at 90°W
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Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	13	6	X	X	X
C	30	20	8	X	X	X
D ₁	40	23	9	(6)	X	X
D ₂	45	28	12	(8)	X	X
D ₃	50	36	17	(12)	X	X
E	55	55	29	20	X	X
F	40	17	6	X	X	X

Rain Attenuation in dB for Satellite at 90°W
(30 GHz)

Zone	Elevation Angle	Percent of the Time Attenuation is Exceeded				
		0.01	0.05	0.1	0.5	1.0
B	35	29	13	(9)	X	X
C	30	45	17	(11)	X	X
D ₁	40	50	21	(14)	X	X
D ₂	45	63	28	(18)	(6)	X
D ₃	50	80	39	(27)	(8)	X
E	55	120	64	43	(10)	X
F	40	37	13	(9)	X	X

KEY: / Normal Operating Margin
 O Adaptive FEC, UL & DL
 △ Adaptive Power, UL

Margins
 PWR 13.3 dB
 FEC 8.8 dB

(83 watts) provides an uplink availability of .999 in all rain zones except rain zone E (triangle case). Thus, the combination of clear weather operating margin, adaptive FEC margin, and adaptive uplink power control will provide an availability of .999 in all rain zones except E. In rain zone E an additional margin of 5.9 dB is required on the downlink and 16 dB on the uplink. Table V-10 gives the link budget for a TDMA CPS system with 128 MBPS uplink and 250 MBPS downlink burst rates. Table V-11 shows the availability achievable in the various rain zones using normal clear weather margin, adaptive FEC, and adaptive UL power control as in the previous examples. In this case the CPS up-link transmitter power must be increased to 25 dBW (316W). Again with the combined margin an availability of .999 is provided in all rain zones except rain zone E.

The additional margin required on the down-link and uplink to achieve a CPS system availability of .999 in rain zone E is 5.9 db and 16 db, respectively. An approach to resolve the problem is:

<u>Downlink:</u>	<u>Margin Gain</u>
decrease burst rate to	
128 MBPS:	2.9 dB.
Increase zone E CPS	
antenna size to 5.0 meters	<u>3.0 dB</u>
TOTAL	5.9 dB

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<u>Uplink:</u>	<u>Margin Gain</u>
- Increase zone E CPS ES antenna size to 5.0 meters	3.0 dB
- Customize UL transmission rate (FDM), for example 6.3 MBPS.	
Normal operation gain increase (vs. 128 MBPS)	7.0 dB
- Additional Adaptive UL Power Margin	<u>6.0 dB</u>
	16.0 dB

The adaptive up link transmitter power required in Zone E is then 26.2 dBW (330W).

The lower CPS DL and UL transmission rates would require on board switching to 128 MBPS TDMA downlinks and the ability to receive demodulate, and decode FDM uplinks. Connectivity between zone E CPS stations and CPS stations in the other rain zones would be accomplished in the on-board base band processor.

Additional study is necessary to identify other alternative design approaches to adequately service high rain rate areas with low cost earth stations.

5.0 NETWORK SYNCHRONIZATION

5.1 GENERAL CONSIDERATIONS

5.1.1 TIMING (FRAME "PHASE" ACQUISITION)

Network synchronization, in any TDMA system requires that stations sharing a transmission channel time their burst(s) per frame so as not to interfere (overlap) with the other channel users. It also implies that the stations have some prior knowledge of when in the frame to receive bursts destined for them; this second aspect (receive timing) is not as critical and is usually solved by placing a "window" of a few bits on either side of the framing location at which the unique word designating start of a burst destined for that station is expected. Transmit timing, on the other hand, especially when utilizing a satellite relay, requires computing of the distance, and thus propagation delay, from each station to the satellite so that burst overlap can be avoided with minimum guard times between allocated burst assignments.

5.1.2 FREQUENCY (FRAME "FREQUENCY" ACQUISITION)

The transmitter data clock at any TDMA station determines the local frame rate (e.g. 128,000 bits per frame for a 128 Mbps channel using a 1 msec frame duration). This clock is usually locked to the station's master oscillator which also determines the RF transmit frequency and the receiver's local oscillator

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frequency at the downconverter. The accurate frequency locking of all network oscillators (including the MO in the satellite) can improve demodulator performance both at the satellite (in the case of a CPS BPU technique) and at the ground station (for both the CPS and trunking networks). This enables the use of narrower filters in the demodulator's carrier and bit timing recovery circuits which in turn enables shorter preambles, for a given Eb/No, at the beginning of each burst. This is desirable in that it increases TDMA throughput since such preambles act as overhead, much the same as guard time. The following paragraphs, however, do not address the required or achievable network frequency accuracies for an operational system. It is felt that accurate frequency locking which includes tracking the satellite doppler frequency shifts will impact the cost of both the MCS and the earth station hardware and will require further analysis and perhaps demonstration during the experimental flight programs.

5.2 TIMING SYNCHRONIZATION - TRUNKING TDMA

5.2.1 CLOSED LOOP SYNCHRONIZATION

A closed loop system for acquiring trunking TDMA transmit burst synchronization can be implemented by having each trunking station transmit a local unique word (LUW) during a satellite switch (SS), "loopback" mode, once per frame. It also requires the MCS which

has acquired the SS to transmit a reference unique word (RUW) to each of the downlink beams at a known position, e.g. at the beginning of each of the modes which connect the MCS uplink beam with each of the downlink beams. Transmit timing is then continuously advanced or retarded to maintain steady state synchronization (a fixed number of bits or symbols between the reception of the RUW and the reception of the LUW. Accuracies of ± 20 nsec (a few symbols) can probably be achieved.

5.2.2 OPEN LOOP SYNCHRONIZATION

Open loop synchronization of transmit burst timing is accomplished by calculating the slant range from each trunking station to the satellite periodically, and interpolating, via a simple range rate calculation, timing adjustments between range fixes (if needed). This requires fairly accurate ranging from two to four trunking stations to the satellite, and can be accomplished with turnaround ranging tones or via looped back unique words at each ranging station. From these (2 to 4) slant range measurements the range from any other trunking station can be simply calculated utilizing a "linearized" approximation to the quadratic range equations requiring only 12 multiplications plus 8 additions per range update. The accuracy of the original range measurements is degraded by at most a factor of two using this technique.

5.2.3 TRUNKING TDMA SYNCHRONIZATION RECOMMENDATION

The open-loop method of Paragraph 5.2.2 is recommended for the following reasons:

1. Ranging will be required in any event for satellite Station Keeping (and perhaps to obtain parameters for computing CPS station open-loop antenna pointing instructions).
2. The need for the (m) mode RUW and the (n) loopback LUW transmissions and associated burst synchronization circuitry is eliminated (where m = number of beams and n = total number of trunking earth stations).
3. The initial accuracy and frequency of update of the slant range measurements can be relaxed (guard time for 100-200 stations does not greatly impact overall frame efficiency) resulting in less expensive MCS processor capability.

5.3 TIMING SYNCHRONIZATION - CPS

5.3.1 CLOSED LOOP SYNCHRONIZATION

The RUW/LUW technique described in Paragraph 6.2.1 is not practical for the CPS network since the uplinks are separated, in time, from the downlink due to BPU processing. A closed loop approach is possible in which the satellite assists by monitoring each uplink channel and counting the number of symbols between start-of-frame to reception of a CPS transmitted UW. This information is then transmitted back to the CPS on its downlink channel. The CPS then simply compares

the satellite measured count with its preassigned burst position count and advances or retards its transmit bursts accordingly.

5.3.2 OPEN LOOP SYNCHRONIZATION

Open loop synchronization can be accomplished for the CPS network exactly as in the trunking network of Paragraph 5.2.2. The required range measurements (or calculated ranges for each station) are transmitted from the MCS to the CPS user via the OW.

5.3.3 CPS - SYNCHRONIZATION TIME RECOMMENDATION

Since the closed-loop technique requires increased BPU logic and complexity, and since there appears to be no "common" trunking/CPS closed loop approach, it is recommended that the open-loop method as described in Paragraph 6.2.2 be employed for the CPS scanning-beam network.

6.0 ASSESSMENT OF DUAL POLARIZATION AT 30/20 GHz

Some experience has been gained in dual polarization operation at the lower frequencies; however, extension of these results to the 30/20 GHz frequencies has not been validated. The experimental data on 30/20 GHz polarization isolation is also quite skimpy. We have based the following assessment on three sources: the NASA Propagation Effects Handbook, data collected with the RCA SATCOM system, and some reference articles that treat the subject.

6.1 PROPAGATION EFFECTS

6.1.1 NASA PROPAGATION EFFECTS HANDBOOK RESULTS

Table V-12 is extracted from the Handbook and shows a number of recommended formulas for computing the cross-polarization isolation at high frequencies. In these formulas, "A" is the attenuation in dB. Using the tables of attenuation calculated previously, we have computed the expected cross-polarization isolation; this is shown in Tables V-13 and -14.

6.1.2 RCA SATCOM RESULTS

Data for the predicted performance of the RCA SATCOM system are shown in Table V-15 for a number of CONUS locations. While these data are for 4/6 GHz, it is possible to scale them upward in frequency.

One researcher (T.S. Chu) has found a relationship to scale polarization isolation by frequency. The formula is valid between 3 and 30 GHz and is as follows:

$$XPI(f_2) = XPI(f_1) - 20 \log(f_2/f_1)$$

for the case of a given value of rain rate. This also corresponds to a given value of percentage of time. Hence, the RCA SATCOM data can be scaled in this way. The results of such scaling for the composite average values shown in Table V-15 are given in Table V-16

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Cross-Polarization Discrimination Versus Attenuation
(Least-Mean-Square Fits)

Blacksburg, VA		Elevation Angle = θ
Period	Frequency/Polarization	$XPD = \tilde{a} - \tilde{b} \log_{10}(A)$
Aug 1977	11 GHz, RHCP (CTS, $\theta = 33^\circ$)	XPD = $44.7 - 22.6 \log_{10}(A)$
CY 1978	11 GHz, RHCP (CTS)	XPD = $36.3 - 16.2 \log_{10}(A)$
Aug 1977	19 GHz, vertical (COMSTAR, $\theta = 44^\circ$)	XPD = $47 - 24.5 \log_{10}(A)$
Sept 1977	19 GHz, horizontal (COMSTAR)	XPD = $37.1 - 20.0 \log_{10}(A)$
CY 1978	19 GHz, vertical (COMSTAR)	XPD = $43.9 - 16.6 \log_{10}(A)$
Aug 1977	28 GHz, vertical (COMSTAR)	XPD = $36.4 - 15.4 \log_{10}(A)$
CY 1978	28 GHz, vertical (COMSTAR)	XPD = $31.2 - 7 \log_{10}(A)$

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Estimated Cross-Polarization Isolation for Various U.S. Sites Due to Rain
(Distribution of Rain Drop Canting Angles Assumed)

Category	Site	β	4 GHz			6 GHz		
			0.01%	0.1%	1%	0.01%	0.1%	1%
2	Boston	21.58	21.5	34.1	40.5	21.2	30.5	37.2
2	New York	21.60	23.5	35.1	41.4	22.1	31.1	38.2
2	Houston	46.72	30.6	39.9	46.3	26.5	36.1	42.6
2	Chicago	32.16	27.8	37.3	43.0	21.1	33.5	40.3
2	Denver	41.79	29.6	39.0	45.1	25.7	35.5	41.8
4	San Diego	51.87	31.9	41.7	47.4	30.8	37.5	43.4
4	Los Angeles	50.47	34.6	41.4	47.1	30.5	37.5	43.1
3	San Francisco	46.10	32.9	40.6	46.2	28.8	36.3	42.5
3	Seattle	35.22	30.8	38.6	41.0	26.9	34.9	40.8
1	Tampa	38.37	26.7	36.9	44.7	22.6	33.2	41.3
Average (Canting Angle Distribution)		29.7	38.5	44.6	25.9	34.7	41.1	
Average (Constant Canting Angle)....		23.7	32.5	38.6	19.9	28.7	35.1	

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Table V-13

Cross-Polarization Isolation at 20 GHz

(dB)

(40° elevation angle)

Climate Zone	0.01	Percent of Time XPI is Exceeded	0.05	0.1	0.5	1.0
B	25	31	34	44	44	44
C	23	30	34	44	44	44
D ₁	21	27	30	39	44	44
D ₂	19	25	28	36	44	44
D ₃	18	23	26	34	39	39
E	15	20	23	34	39	39
F	24	32	36	44	44	44

Table V - 14

Cross-Polarization Isolation at 30 GHz

(dB)

(40° elevation angle)

Climate Zone	0.01	Percent of Time XPI is Exceeded	0.05	0.1	0.5	1.0
B	21	23	25	28	29	29
C	20	23	24	28	29	29
D ₁	19	22	23	26	29	29
D ₂	18	21	22	26	28	28
D ₃	18	20	21	25	27	27
E	17	19	20	24	27	27
F	20	24	25	28	29	29

Table V-16
RCA SATCOM Data
(Scaled to 20/30 GHz)

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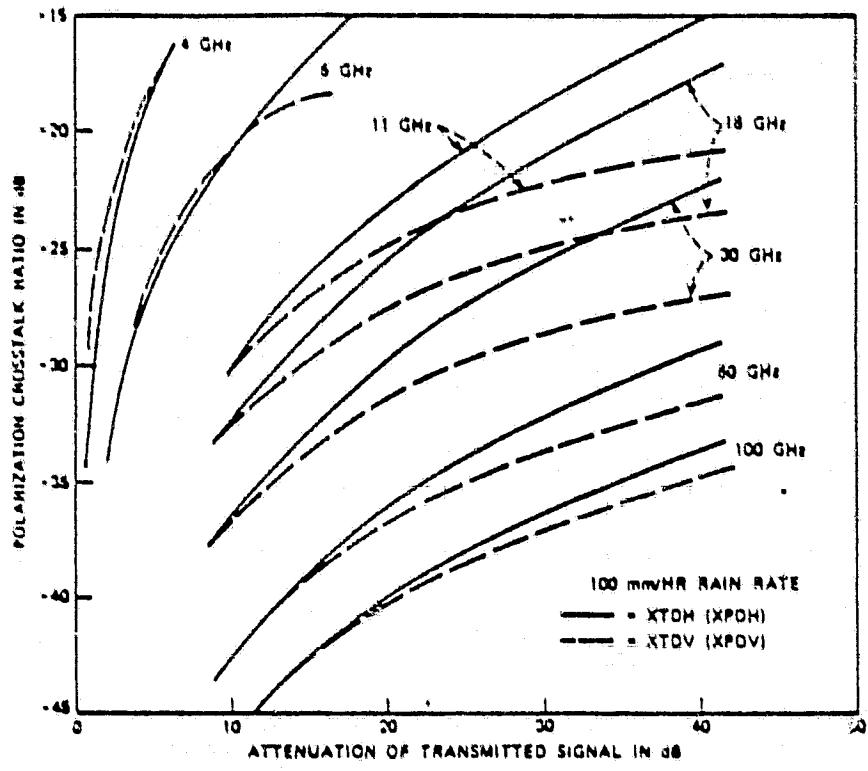
	Percent of Time XPI Is Exceeded		
	0.01	0.1	1.0
20 GHz	16	25	31
30 GHz	12	21	27

These values compare favorably with those presented in Tables V-13 and -14. It should be noted that data on frequency scaling of such values is even skimpier than that for the direct calculation of cross-polarization. Earlier calculations by Chu, which are shown in Figures V-1 through V-3, demonstrate the general variation of cross-polarization with attenuation. The independence of the isolation from rain rate (for a constant attenuation) is also shown.

6.1.3 CONCLUSIONS

Rain caused depolarization should not prove to be a problem at 30/20 GHz. The main reason for this is that the attenuation caused by rain becomes severe at much lower rain rates than does the depolarization. The digital systems which are contemplated for the 30/20 GHz bands, particularly those employing coding,

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CALCULATED RAIN-INDUCED CROSS-POLARIZATION
OF HORIZONTALLY AND VERTICALLY POLARIZED WAVES

Figure V-1

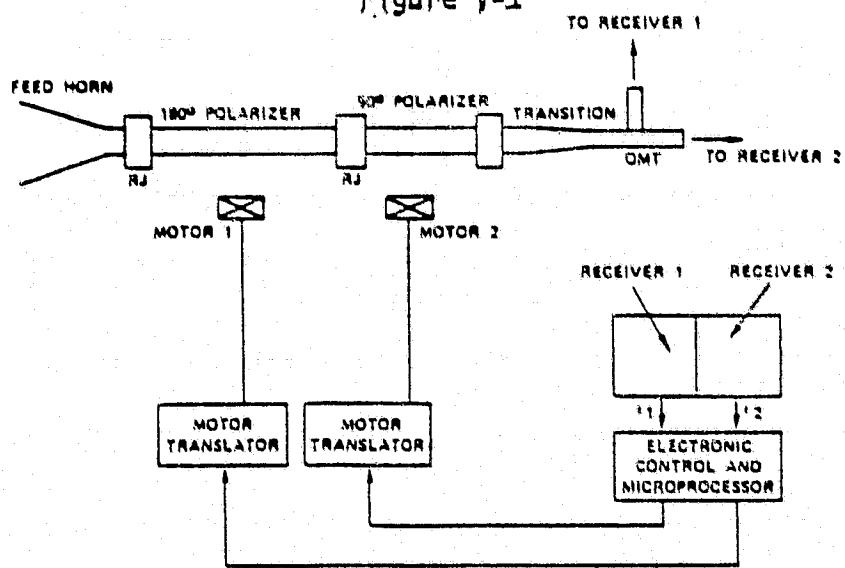


Figure V - 4

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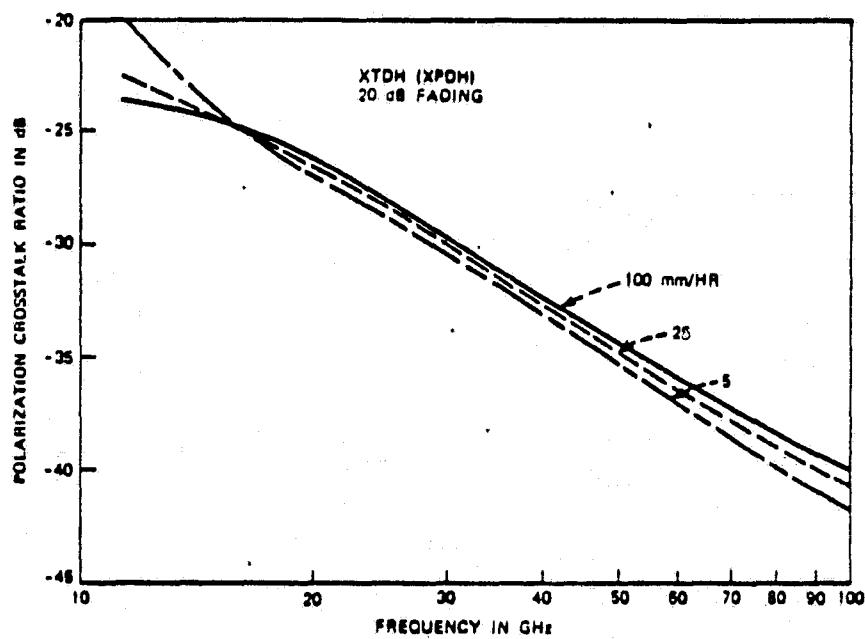


Figure V - 2

CROSS-POLARIZATION AT 20-dB FADING
FOR VARIOUS RAIN RATES

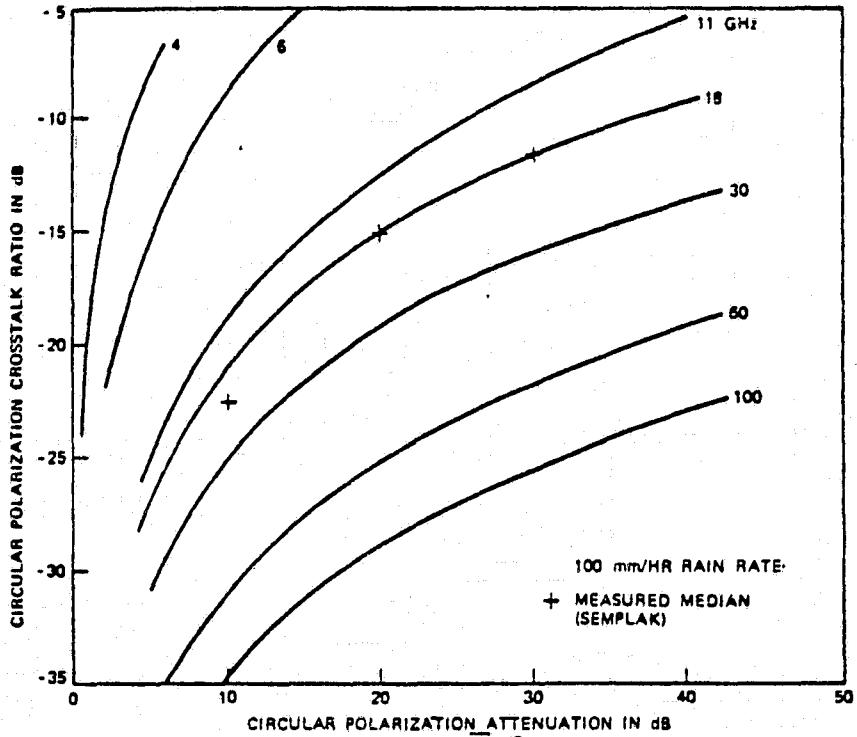


Figure V-3

CALCULATED RAIN-INDUCED CROSS-POLARIZATION
OF CIRCULARLY POLARIZED WAVES

should be able to withstand cross-polarization interference at a -20 dB level without significant degradation. This provides an availability of about 99.95 percent.

6.2 CROSS-POLARIZATION PERFORMANCE OF ANTENNAS

Generally, the cross-polarization isolation of antennas is greatest at beam-center, and degrades as the scan angle increases. In actual antennas, the maximum of the cross-polarization isolation will not occur exactly on-beam, due to imperfections in the antenna and feed structure. This angular error is generally small in well-designed antennas.

For the earth station antenna, the above is of relatively little importance, since the tracking system can keep the pointing within tolerable bounds. For the spacecraft antenna, this degradation of polarization isolation is significant due to the multibeam or scanning beam system employed. Both systems need (relatively) larger scanning angles than would otherwise be encountered. While it is apparent that the antenna design will be complicated by this consideration, it is impossible to say (at this time) if the required levels of isolation can be achieved in practice.

6.2.1 POLARIZATION TRACKERS

Two polarization tracking mechanisms have been developed for satellite earth station use: one at COMSAT Labs, and another at NASA/Langley Research Center.

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Both systems are motor-driven. The COMSAT system has been built and tested at 4 GHz; the NASA system is patented, and therefore must have involved a working prototype. No information concerning the frequency of operation is given.

The COMSAT adaptive polarization connection network is simpler of the two. It corrects for differential phase but not for differential attenuation; this is consistent with the C-band design. At C-band, differential attenuation is negligible because the fundamental attenuation is so low. At higher frequencies this would not be true, and a more complex correction system would be needed.

A block diagram is shown in Figure V-4. The system requires two CW beacons, one at each polarization, to be transmitted from the satellite. It is necessary to incorporate a microprocessor in the system because the relationship between the polarization errors and the position of the two rotatable polarizers is not a simple one, ruling out the use of direct feedback control. The microprocessor is capable of resolving the complex functions involved.

For the linear polarizations, and in systems where cost is a significant consideration, we expect that a simplified version of such a network may be developed. This would provide a reduction in cross-polarization with a reduced cost.

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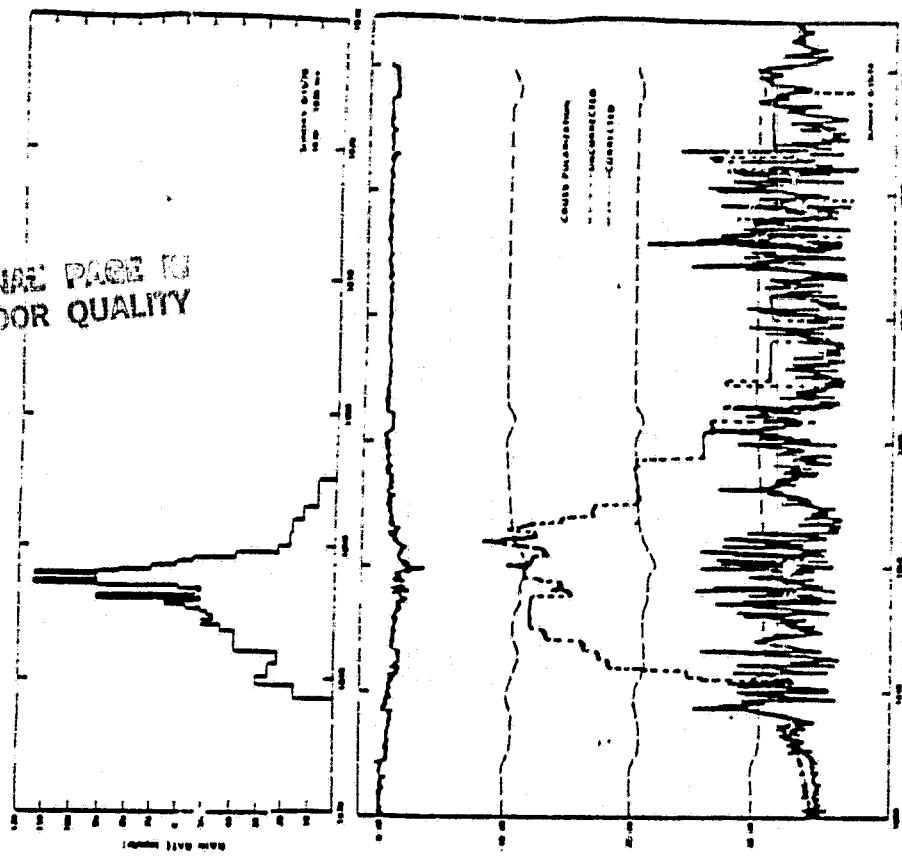


Figure V-6

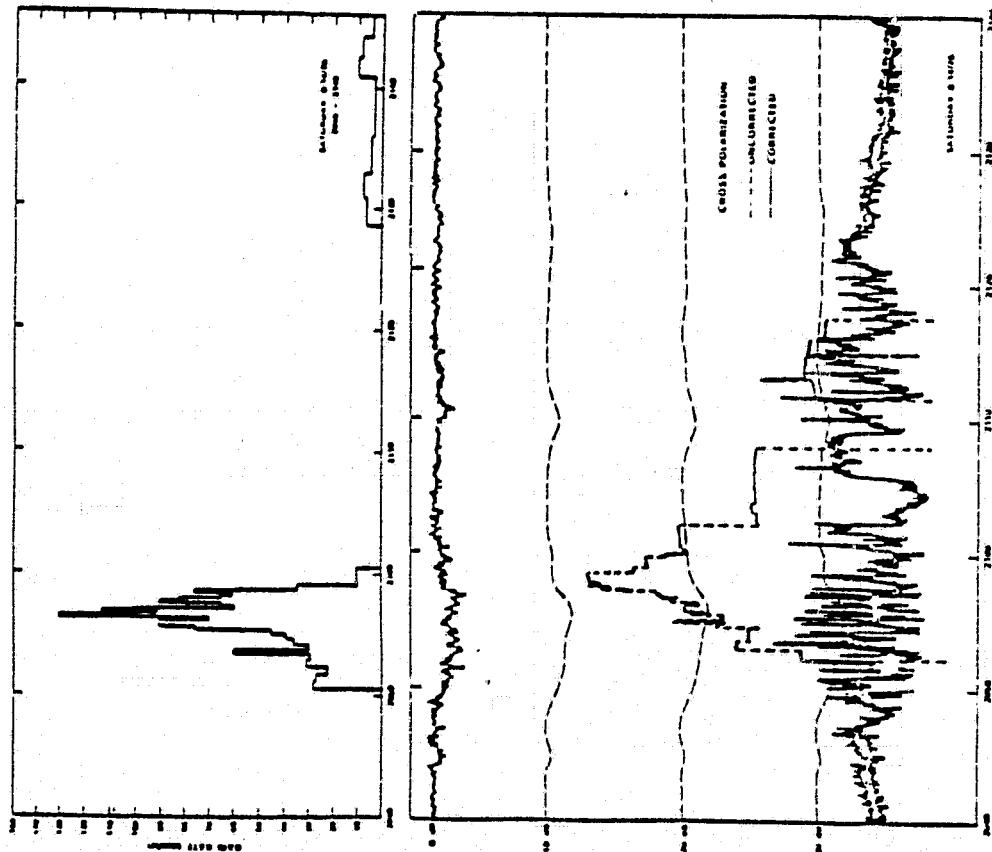


Figure V-5

Some of the experimental results for this polarization correction network are shown in Figures V-5 and V-6. Long-term statistical figures for the system have not been published. However, if the correction network proves to be reliable, the degree of correction shown in the figures, about 15 dB maximum, should be approached on a long-term basis.

The NASA/Langley polarization correction network is more complex. It is also adaptive, and involves motor-drive. This system features active cancellation of the cross-polarized component. The implementation also requires two CW pilots for operation. A block diagram is shown in Figures V-7 and V-8.

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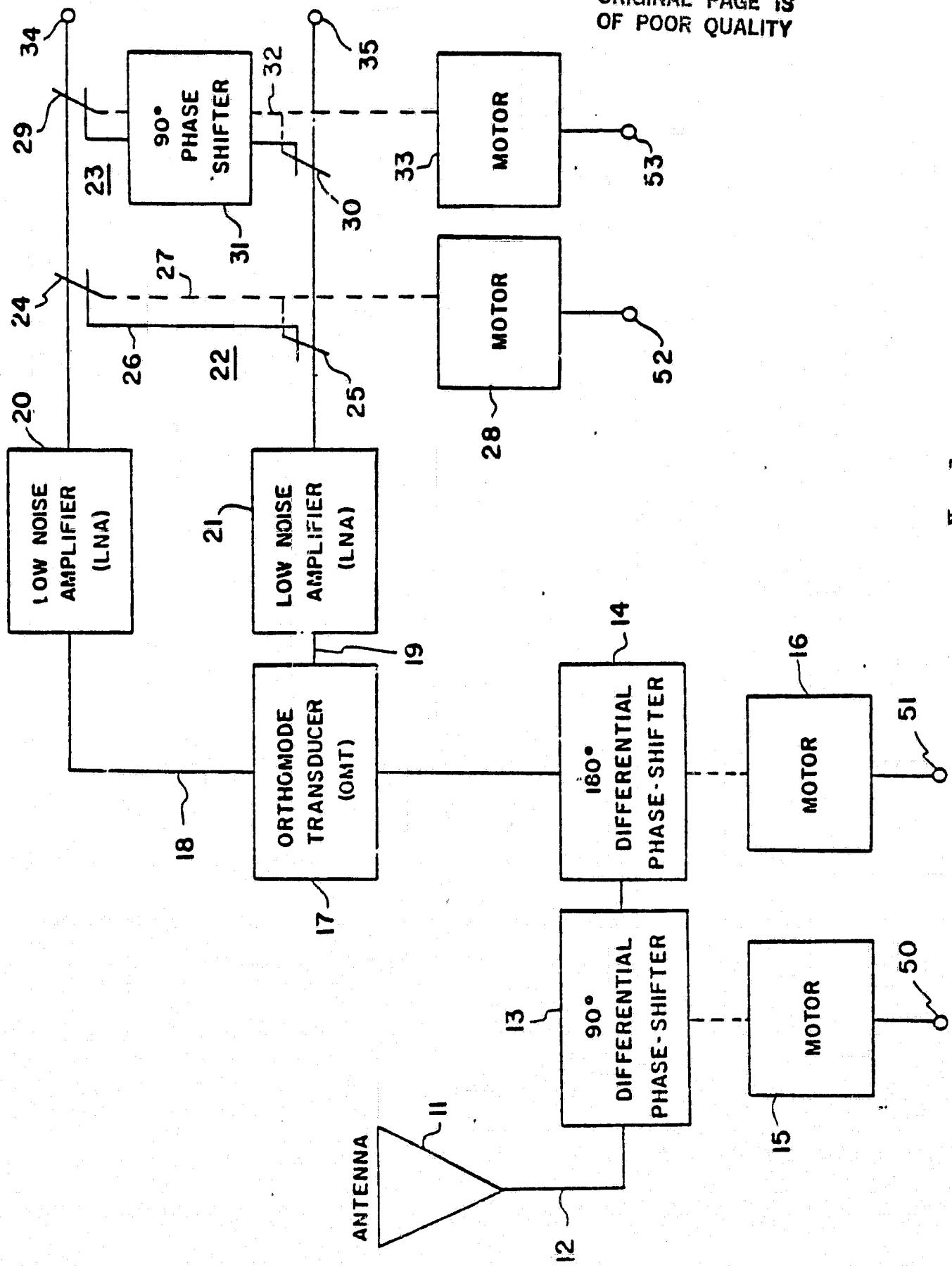
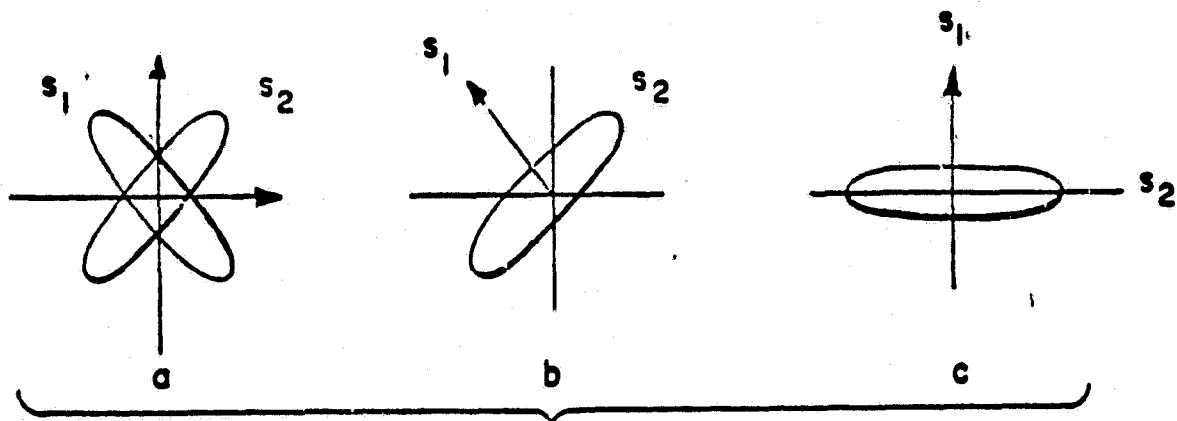


Figure V - 7



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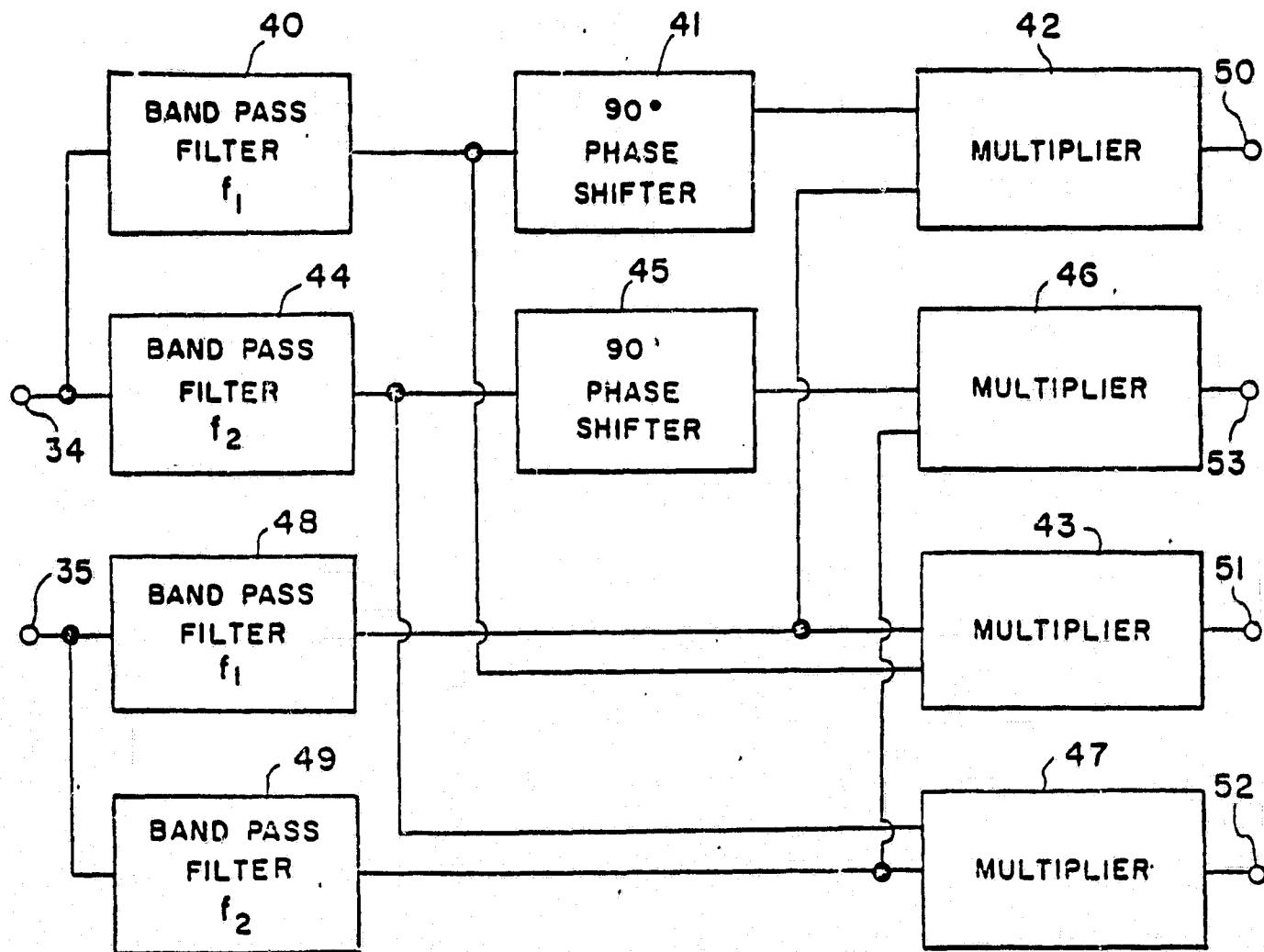


Figure V - 8

OPERATIONAL SYSTEM FUNCTIONAL REQUIREMENTS1.0 STATEMENT OF THE PROBLEM

The purpose of this section is to derive a consistent set of functional requirements for the space, ground, and control segments of a Western Union class carrier operational 30/20 GHz system. These should meet the primary objectives of capacity, availability, inter-connectivity, and cost for a selected baseline system based upon a projected share of the accessible market in the 1990-2000 period.

2.0 INTRODUCTION

The baseline system chosen, as a result of the analyses of traffic, availability, and general technical considerations in Sections I through V, provides a combined Trunking and CPS service with an expected throughput capacity of about 4 GBPS trunking and 2 GBPS CPS.

The functional requirements for the two services are derived separately, although the technical solution for the combined system will be optimized by the development of elements common to both services. For example, in the space segment, the CPS users located in the fixed trunking beam areas can access the same beams (possibly on a separate frequency); similarly, smaller trunking terminals, not covered by a fixed beam, can access one of the CPS scanning beams. Also many control station functions such as network synch-

ronization, antenna pointing and satellite switch programming will have commonality between the trunking and CPS services.

3.0 METHODOLOGY

The achievable satellite characteristics of the TRW and Hughes Baseline System Concepts (number and size of antenna beams, available RF power at 20 GHz, weight limitations, etc.) were combined with the Earth Station characteristics (reasonable antenna size, HPA power, LNA noise temperatures, etc.) to derive the uplink and downlink budgets shown in Sections IV and V. Network control functions, including architectures, derived in the Ku-band Advanced Westar program, where applicable, were then added to develop a coherent set of functional requirements.

Frequency re-use through spatially separated spot beams will provide more than enough total bandwidth to meet the total 6 GBPS throughput capacity for the combined Trunking and CPS services. Thus, from the point of view of a single user (carrier), frequency re-use through polarization, that is the use of two orthogonal polarizations at the same frequencies in the same or overlapping beams, is not required.

However, the prime portion of the orbital arc, resulting in elevation angles of about 30°, is limited to about 15°. Several carriers, each with 2 or more satellites, will all want to be located in this prime

portion. Thus orthogonal polarization was considered for the operational system, and the corresponding requirements listed where applicable. Whether or not the operational system can utilize some degree of polarization re-use of course will ultimately depend on the test results from the Demonstration System, but it is certainly a most desirable goal and therefore should be included at this time for an operational system.

The need for an intersatellite link, although useful for extending the Ka-Band orbital arc as well as providing interconnectivity with other networks, will not be considered as part of this Trunking/CPS baseline operational system. However it can remain a viable candidate for the Demonstration System.

4.0 GENERAL OPERATIONAL SYSTEM DESCRIPTION

The baseline operational system that can meet Western Union's requirements for capacity, connectivity, availability and minimum overall system costs is summarized here.

4.1 TRUNKING SERVICE

The basic trunking service is provided by 18 fixed, .3° beams each connected to a 500 MHz, dual output power (75W/10W) transponder. Even if orthogonal polarization proves to be unfeasible, three separate carrier frequencies (each with 500 MHz bandwidth), each reused on 6 of the fixed beams, should provide the

required C/I through adequate sidelobe isolation, as specified below. Thus a frequency re-use factor of six is achieved. Complete trunking interconnectivity is provided using 500 Mbps, Satellite Switched TDMA channels which requires a 20 x 20 IF switch matrix in the satellite, programmable from a Master Control Station to satisfy changing traffic patterns. Although the maximum throughput is 9 Gbps, this will only be achievable for a completely balanced traffic pattern, i.e. the sum of all the traffic demands at each station would have to be 500 Mbps.

A more realistic achievable throughput, including secondary trunking stations serviced by scanning beams as described below, should be about 4 GBPS.

4.2 CPS SERVICE

The basic CPS service can be provided by the additional satellite payload of six 500 MHz transponders, each with two 75 watt TWTA's connected to one .3° scanning beam. To reduce off-axis scanning losses 3 beams will scan Eastern CONUS and 3 beams will scan Western CONUS for a frequency re-use factor of three.

Uplinks will use FDM to provide subchannel combinations of 32 Mbps and 128 Mbps burst rates (eg. three 128 Mbps and four 32 Mbps uplinks per beam). Each uplink subchannel in turn can utilize TDMA to accommodate sub-groups of CPS users, within a common scanning beam position, whose aggregate throughput is

less than or equal to 128 Mbps or 32 Mbps. The down-links will use two 256 Mbps TDMA carriers per beam. The uplinks are routed through down converters to a Baseband Processor which demodulates and performs FEC decoding (if required by uplink rain attenuation). The baseband processor then routes each burst to the assigned downlink via an FEC encoder (if required by downlink rain attenuation), a 256 MBPS modulator, an upconverter, and a 75 watt TWT that feeds the scanning beam downlink. Although the 6 transponders represent a maximum CPS throughput of 3 GBPS, because of the multiple uplinks (up to seven per scan position) and downlinks (two per scan position), it will be very unlikely that the CPS geographical traffic demand will utilize the full throughput. The realizable throughput will be about 2 GBPS.

4.3 TRUNKING/CPS CROSS-CONNECT CONSIDERATIONS

Secondary trunking stations (not located in the 18 fixed-beam areas) can be added to the trunking Network and serviced by the scanning beam. One of the three East scanning beams will "visit" each of these smaller trunking stations once per TDMA frame, and similarly one of the West scanning beams is assigned to service those smaller trunking stations which are in the Western area. In the satellite these uplink/downlink signals are coupled to the receiver input/TWT output of one or two of the least-used 18 fixed-beam

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transponders; it is only necessary to program the receive/transmit TDMA bursts of these additional trunking stations and that of the fixed-beam transponder(s) so that they do not overlap at the satellite. No on-board CPS-trunking cross-connect, with its attendant drain on the Baseband Processor Unit (BPU) throughput capacity, should be necessary to serve presently identified requirements. Instead, any required CPS-trunking cross-connections will be established on the ground at one or more trunking stations having co-located CPS terminals (see below). While this does introduce extra delay for the affected circuits, the overall system effects will not be significant and the reduction in satellite complexity is an important consideration.

CPS users located within fixed-beam areas, but not colocated at trunking stations should be serviced by the scanning beam in the same manner as the CPS users not in fixed-beam areas. This alleviates the coordination between the two services which would be required if the fixed-beam CPS users shared the trunking frequency channel on a TDMA basis; it also alleviates the linearity requirement if the satellite trunking transponders had to accommodate multiple FDM uplinks (e.g. three 128 MBPS and four 32 MBPS simultaneous uplinks). Also many of these "fixed-beam" CPS users can be expected to be located within the coverage area

of high-capacity trunking terminals (e.g. New York, Chicago, Los Angeles) which could be filled to their 500 MBPS throughput capacities.

For CPS users co-located (or connected by terrestrial local loop) to a trunking terminal, two approaches can be considered. The first approach is to add CPS ground equipment (HPA, LNA, up/down converters, modems and codecs) to one of the pair of space-diversity trunking stations, in which case these CPS users are serviced like all other CPS users. Thus no additional antenna is required. The second approach would be to share the trunking up/down links on a TDMA basis which would cause increased cross-connect complexity in the spacecraft payload. For the reasons stated in the preceding paragraph, the first approach is recommended at this time. At the most, it would require equipping only 18 main trunking terminals with CPS transceivers, which would have a negligible impact on total system costs.

4.4 SUMMARY OF PERFORMANCE OBJECTIVES

4.4.1 THROUGHPUT CAPACITY

The maximum realistic throughput capacity for the first Western Union class system to serve the accessible 30/20 GHz market has been estimated in Section II at 4 Gbps Trunking and 2 Gbps CPS.

4.4.2 LINK AVAILABILITY

The uplink and downlink rain margins are sized to

achieve an availability of .9999 for Trunking and .9950 to .9990 for CPS service at a user BER of 10^{-7} .

4.4.3 TDMA SYNCHRONIZATION

Open loop synchronization, utilizing slant range measurements from (up to) 4 trunking stations sent to all Earth Stations via Order Wire from the Master Control Station (MCS) will provide TDMA burst synchronization. In addition the Master Frequency Generator (MFG) in the spacecraft will be frequency controlled (using a disciplined PLL) by uplink command from the MCS, so that the only significant frame-to-frame timing and frequency error contributions will be due to satellite motion. These will be tracked out utilizing computed range rate at each station. The combined guard-time plus preamble (required for carrier and bit-timing recovery of the demodulators) should be less than 500 nanoseconds for the initial operating system. For a 1,000 station CPS network accessing the 6 CPS scanning beams, each with two 256 MBPS downlinks, there will be an average of 83 CPS users per TDMA downlink. Since each CPS users needs to burst once per frame there will be $83 \times 500 \text{ nsec} = 41.5 \text{ usec}$ lost for guard-time/preamble per 1,000 usec frame (1 KHz frame rate). This represents an average TDMA frame efficiency of over 95%. The allocation of the 500 nanoseconds between guard-time and preamble depends upon the accuracy and frequency of the range measurements and will

also be influenced by the settling time of the scanning beam at each spot position. If many more than 1,000 CPS users per satellite are deployed at a later date, the ranging and frequency accuracy can then be increased to maintain TDMA frame efficiency.

4.4.4 CONNECTIVITY

Full interconnectivity will be possible between all pairs of Trunking stations via a 20 x 20 Satellite Switch. Full interconnectivity is required for the CPS service and is provided by the Baseband Processor, with reprogrammable routing under control of the MCS. No absolute requirement for Trunking/CPS interconnectivity in the Satellite Baseband Processor has been identified at this time; the interconnectivity can be provided at the Trunking Stations.

Similarly, although DAMA 64 Kbps channel reassessments can be made by the MCS via the satellite Baseband Processor, this capability does not have to be implemented at full speed and maximum throughput efficiency in the initial system.

4.4.5 THIN-ROUTE CONSIDERATIONS

Until CPS station costs come down to under \$50,000, it is unlikely that stations with less than 24 voice-channel capability (1.5 MBPS) can be justified; this implies that the first few hundred CPS stations will employ some degree of concentration of low capacity users within a local area. Thus the initial system will not have "tailored" low bandwidth up/down links.

4.4.6 FREQUENCY PLAN

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As described in Paragraphs 4.1 and 4.2, there will be 3 trunking channels and 2 CPS channels each approximately 500 MHz wide. If orthogonal polarization is used, the total spectrum occupancy can be reduced by half to 1.25 GHz. This may require dual feeds at some of the Earth Stations depending upon the outcome of the polarization re-use experiment. In addition a ranging/command and a Telemetry link of approximately 1 MHz bandwidth each will be required. Step-track at all of the Trunking stations and at some of the CPS stations may require a beacon other than the telemetry carrier, that is at a lower frequency (S or C Band), so that these stations may continue to track properly during rain conditions.

5.0 OPERATIONAL SYSTEM FUNCTIONAL REQUIREMENTS

5.1 TRUNKING SERVICE

5.1.1 TRUNKING - SATELLITE COMMUNICATIONS SUBSYSTEM

5.1.1.1 NUMBER & SIZE OF BEAMS

The satellite will provide 18 fixed-beams of .3° beamwidth pointed towards the 18 largest trunking station cities plus two scanning-beams of .3° beamwidth of which at least one can be pointed to any one of a set of contiguous positions covering the CONUS area. One scanning-beam can service half of CONUS, and the other service the remaining half, to reduce off-axis scanning losses. Scanning beam positioning will occur at

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a repetitive frame rate (1 KHz) programmable by ground command. See Section 5.2.1 for other scanning beam parameters.

5.1.1.2 CONNECTIVITY

The satellite will provide a 20 x 20 matrix switch at the IF frequency which will allow 500 Mbps QPSK Trunking interconnectivity of any uplink beam to any downlink beam. The switch will repeat each connectivity state (mode) at the frame rate (1 KHz) with a maximum of 100 modes per frame.

5.1.1.3 TRANSPONDERS

One transponder of 500 MHz nominal bandwidth will be provided for each beam. This will have dual output power at 20 GHz of 75w or 10w switchable by ground command to provide downlink rain response. A common IF frequency, selected to minimize spurious inband modulation products, will be used to allow the TDMA switch to connect the receive half of each transponder to the transmit half of any transponder. The trunking TWTA's will operate near saturation, since intermodulation is not a problem with a single carrier per transponder.

The frequency response and linearity of each transponder will be controlled over the central 315 MHz so that for any of the $20 \times 20 = 400$ paths, and for a received flux density input range of 20 dB, there will be an acceptable BER degradation for TDMA 500 Mbps

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QPSK modulation. These specifications cannot be determined until the ground segment's frequency response and linearity are also budgeted, but critical parameters which must be controlled are:

- Amplitude Flatness
- Group Delay
- AM-to-PM Conversion
- Phase Noise
- Out-of-Band Response

5.1.1.4 SATELLITE EIRP

The EIRP for each trunking beam will be ≥ 66.95 dBW for the High Power Mode and ≥ 58.2 dBW for the low Power Mode. The satellite power supply will be sized to enable continuous operation of an average of one transponder in the high power mode. That is, for 20 beams, the worst-month 20 GHz rain margin will require downlink high-power for an average of about 1 hour per day per beam.

5.1.1.5 SATELLITE G/T

The Satellite G/T for each trunking beam will be ≥ 21.4 dB/ $^{\circ}$ K.

5.1.1.6 FIXED-BEAM ANTENNA PATTERNS

The fixed-beam antenna patterns will provide sidelobe isolation ≥ 30 dB between co-channel beams within their 3 dB contours on the same polarization and (if polarization frequency re-use is employed) ≥ 35 dB clear-sky isolation between orthogonal polarizations within the same beam.

The fixed-beam pointing will be maintained to within one-fourth beamwidth (one-half beamwidth during station keeping maneuvers) on all beams by automatic control of the spacecraft's attitude via monopulse tracking feeds on at least three beams. The nominal pitch, roll, and yaw offsets from an earth-centered coordinate system will be changeable by ground command.

5.1.1.7 SATELLITE MASTER OSCILLATOR

The satellite master oscillator (MO) provides all up and down converter local oscillator frequencies and the frame and mode timing for the 20 x 20 TDMA switch. The MO will be frequency controlled by ground command from the MCS using a "disciplined PLL" technique. The short term frequency stability of the MO will be $\leq 1 \times 10^{-11}$ per second.

5.1.1.8 TELEMETRY AND COMMAND

Critical parameters will be continuously telemetered to the MCS on a separate Telemetry downlink channel, possibly including uplink received power levels for each beam.

A separate uplink command channel will be provided to enable MCS control of TWTA High/Low Power Modes, Satellite Switch Mode Sequence, Scanning Beam pointing for the Secondary Trunking stations, MO frequency control, attitude control bias offsets and other "housekeeping" functions including switching in redundant units.

5.1.1.9 REDUNDANT UNITS

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The fixed beam transponders should have common units enabling a 1-for-N redundancy for failed units. N is to be determined based on payload weight constraints and unit reliability. Units in critical paths such as the n x n Satellite Switch and the MO should have at least 1 for 1 redundancy. All redundant units are switchable by ground command.

5.1.2 TRUNKING - GROUND TERMINALS

5.1.2.1 SPACE DIVERSITY

Space diversity earth-station pairs, spaced by 8 to 10 km are required at each Trunking node. A terrestrial diversity interconnect link and diversity switch will be implemented between the station pairs.

5.1.2.2 TRANSMISSION MODE

The trunking stations will operate at 500 Mbps QPSK TDMA on both uplink and downlink. TDMA burst synchronization will be achieved "open-loop" via MCS slant range measurements and "linearized" range calculation for each station. The TDMA MUX will provide elastic storage so that the low-speed user interfaces can be assembled into high-speed TDMA transmit burst. The inverse operation will be provided for TDMA Receive bursts. A station will be able to transmit and receive up to 40 bursts per frame.

5.1.2.3 EARTH STATION ANTENNA

The maximum antenna diameter will be 7.0 meters.

Dual, orthogonal linear polarization feeds and/or polarization tracking may be required at some trunking stations, if polarization frequency re-use is employed. Antennas will employ step-tracking to maintain a pointing accuracy of one-fourth the half-power beam-width for steady-state winds at 30 mph with gusts up to 45 mph. The results of diversity-pair site experiments will determine whether the wind-loading may be relaxed (over that normally required at a single site).

5.1.2.4 STATION EIRP

The station EIRP will be ≥ 79 dBW in the Low Power Mode and ≥ 83.8 dBW in the High Power Mode. The High Power Mode may be switched in or out for uplink rain response at each station as a result of downlink power monitoring or by command override by the MCS via the network Order Wire.

5.1.2.5 STATION G/T

The station G/T will be ≥ 28.6 dB/ $^{\circ}$ K.

5.1.2.6 EQUIPMENT RELIABILITY

The trunking terminal equipment shall have an availability consistent with the rain margin availability of .9999. This would normally require completely, redundant units (except for the antenna) at each trunking station. However it may be possible to utilize the diversity link itself to provide some of the required redundancy, depending on the success of the diversity experiments.

5.2 CPS SERVICE

5.2.1 CPS - SATELLITE COMMUNICATIONS SUBSYSTEM

5.2.1.1 NUMBER AND SIZE OF BEAMS

The satellite will provide 6 scanning-beams of .3° beamwidth which together can be pointed to any one of a set of contiguous positions covering the CONUS area. To reduce off-axis scanning losses, the three scanning beams will each have the capability to cover half of CONUS and the other set of three will each have the capability to cover the remaining half of CONUS. The scanning beams' pointing will occur at a repetitive frame rate (1 KHz) with dwell times at each position programmable by ground command from the MCS.

5.2.1.2 CONNECTIVITY

Transmission channels will be Frequency Division Multiplexed (FDM) to provide up to seven channels per uplink beam (three at 128 MBPS and four at 32 MBPS) and two channels per downlink beam (each at 256 MBPS). Each uplink or downlink channel can in turn operate in a TDMA mode to accommodate multiple users per channel. Each uplink channel can be connected to any downlink channel through the Baseband Processor Unit (BPU).

The BPU will provide the following functions:

- Demodulation of each uplink channel
- FEC Decoding ($R=1/2$, $K=7$, Soft Decision)-
Switchable by Ground Command.
- Routing (including buffering and switching)-
under control of instructions determined by
ground command.

- FEC Encoding ($R=1/2$, $K=7$) - Switchable by ground command.
- Modulation of each downlink channel.

There will be a maximum of eighteen 128 MBPS and twenty-four 32 MBPS uplink channels to be demodulated and twelve 256 MBPS downlink channels to be modulated by the BPU, due to the FDM subchannels formed by the 6 scanning beams. For rain response, a minimum of 8 decoders and 4 encoders should be available to be switched into any uplink or downlink channel respectively. Routing will be quantized in units of 64 KPS channels referred to the user rate, i.e. 64 bit blocks at the TDMA frame rate of 1 KHz. Thus any 64 KBPS sub-burst on an uplink channel can be routed to any downlink channel. The BPU will assemble all traffic destined for a particular downlink channel so as to require the minimum number of downlink bursts per frame per channel.

Connectivity to rain zone E requires further design study to develop an optimum approach. The increased margin can be obtained by tailoring uplinks and/or increased earth station antenna size.

5.2.1.3 TRAI SPONDERS

For each of the 6 scanning-beams there will be one equivalent transponder of 500 MHz nominal bandwidth and continuous output power at 20 GHz of two 75 watt power amplifiers. The input and output halves of the

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transponders are connected via the BPU as described in Paragraph 5.2.1.2. The two CPS TWTA's are coupled at their outputs and routed to a single 20 GHz feed to form the two 256 Mbps downlink channels per beam; thus with only a single TDMA carrier per TWT operation near saturation will be possible.

The frequency response and linearity of each transponder will be controlled over the central 20 MHz, 80 MHz and 160 MHz for the 32 MBPS, 128 MBPS and 256 MBPS channels respectively to minimize overall BER vs Eb/No degradation. Critical parameters to be controlled include:

- Amplitude Flatness
- Group Delay
- AM-to-PM Conversion
- AM-to-AM Conversion (uplink channels)
- Phase Noise
- Out-of-Band Response
- Adjacent Channel Interference (Downlink Channels).

5.2.1.4 SATELLITE EIRP

The EIRP for each of the two downlinks of each scanning beam will be ≥ 64.3 dBW at all scanned positions.

5.2.1.5 SATELLITE G/T

The satellite G/T for each scanning-beam will be ≥ 20.5 dB/ $^{\circ}$ K.

5.2.1.6 SCANNING-BEAM ANTENNA PATTERNS

The scanning-beam antenna patterns will provide side-lobe isolation ≥ 30 dB between co-polarized, co-channel beams within their 3 dB contours, whenever the beam pointing positions are separated by at least .9° (three beam widths) and, if polarization frequency reuse is employed, ≥ 35 dB clear sky isolation between orthogonally-polarized co-channels within the 3 dB contour of the same beam.

Scanning-beam pointing accuracy will be maintained to within one-fourth beamwidth (one-half beamwidth during station keeping maneuvers) by automatic control of the spacecraft's attitude via monopulse tracking feeds on at least three (fixed) beams and by control of the phase-shifters at each feed element if necessary. The total number of scanning-beam steerable positions will be such as to allow complete CONUS coverage with the minimum percentage of metropolitan areas located on the beam edges.

5.2.1.7 SATELLITE MASTER OSCILLATOR

The satellite MO is described in 5.1.1.7. The MO may also be used to assist in the carrier and bit-timing recovery circuits of the uplink demodulators, depending upon the CPS stations' ability to (1) maintain their own frequency accuracy (with respect to the frequency standard of the MCS) and (2) track out Doppler due to satellite motion. For the initial net-

work, this CPS capability will probably not be implemented, and therefore the demodulators should not depend upon a long term relative stability between the MO and the CPS uplink frequencies of better than 10^{-7} .

5.2.1.8 TELEMETRY AND COMMAND

The Telemetry link will send status of critical parameters to the MCS, possibly including received uplink power for each channel and uplink BER indications for those channels which have the FEC decoders switched in.

The uplink command channel will enable MCS control of the FEC decoders and encoders, scanning-beam pointing commands for the 6 scanning beams, MO frequency control, routing instructions to the BPU, attitude-control bias offsets, and other "house-keeping" functions including switching-in redundant units.

5.1.1.9 REDUNDANT UNITS

The scanning-beam transponders should have common units enabling a 1-for-N redundancy for failed units. Critical paths such as the BPU and the MO (plus related frequency synthesizers) should have at least a 1 for 1 redundancy. All redundant units are switchable by ground command.

5.2.2 CPS - GROUND TERMINAL

5.2.2.1 SPACE-DIVERSITY

Space diversity normally will not be required at CPS

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ground stations to meet the link availabilities of .995 to .999. However larger capacity stations located in Rain Zone E may be able to justify a diversity terminal pair.

5.2.2.2 TRANSMISSION MODE(S)

The CPS station will operate its uplink at either 128 MBPS or 32 MBPS QPSK TDMA with or without an FEC encoder ($R=1/2$, $K=7$). Downlinks will operate at 256 MBPS QPSK TDMA. Scanning beam and TDMA burst synchronization will be achieved "open-loop" via MCS derived slant range measurements and "linearized" range calculation for each station. The TDMA Mux will provide user rate to burst rate data conversion and assembly on transmit and the inverse functions on receive. A station will be able to transmit and receive up to 4 bursts per frame.

5.2.2.3 EARTH STATION ANTENNA

The normal maximum antenna diameter will be 3.5 meters. If polarization frequency re-use is used, dual orthogonal linear polarization feeds and/or polarization tracking may be required at some CPS stations. Antennas will employ either step-tracking or "commanded" tracking (open loop). Antennas will maintain a pointing accuracy of one-half the half power beamwidth for steady state winds of 60 mph with gusts up to 80 mph.

5.2.2.4 STATION EIRP

The station EIRP will be ≥ 66.8 dBw in the Low Power Mode and ≥ 80 dBw in the High Power Mode. The High Power Mode may be switched in or out for uplink rain response by remote control of the MCS for unattended stations.

5.2.2.5 STATION G/T

The station G/T will be ≥ 23.0 dB/ $^{\circ}$ K.

5.2.2.6 EQUIPMENT RELIABILITY

The CPS terminal equipment shall have an availability $\geq .999$. This may require redundancy of critical elements.

5.3 MASTER CONTROL STATION

5.3.1 RANGING, TRACKING AND SYNCHRONIZATION

The MCS will track the 30/20 GHz satellite for the purposes of:

- (1) Planning and executing periodic station-keeping maneuvers (design goal is $\pm .05^{\circ}$ North-South and $\pm .05^{\circ}$ East-West)
- (2) Providing network synchronization for TDMA operation in both the trunking and CPS systems.

Slant range from each of four trunking stations to the satellite will be measured to an initial accuracy of ≤ 200 nanoseconds. Two-station turn-around ranging signals generated at the MCS (colocated with one of the trunking stations) may be used in cooperation with three other trunking stations; alternatively, the

transmission and reception of a TDMA Unique Word from each of the four stations may be used to measure the slant ranges.

The MCS will compute the satellite's ephemerides (State Vector) from the four slant ranges at least once per minute. It will then transmit this ephemeris, together with at least three of the four slant ranges to each network station via the network Order Wire (OW). Each station will then compute its own slant range to an initial accuracy of ≤ 200 nanoseconds; alternatively the MCS may make the individual station-to-satellite slant-range calculation, in which case the MCS would transmit these slant ranges to each network station via the OW.

At unattended CPS stations, employing commanded antenna pointing (open-loop), the MCS may also compute the local azimuth and elevation angle, for each station and transmit these as pointing commands to the station's antenna subsystem.

The MCS derived range measurement accuracies and computational speed should be capable of eventual growth, so that for a fully deployed network with 1,000 to 10,000 stations range and range rate accuracies can be improved by a factor of at least 100 to minimize inefficiencies due to guard times and/or preambles in a TDMA network with 100 to 1,000 accesses per beam per frame.

5.3.2 ROUTING CONTROL

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5.3.2.1 TRUNKING

The MCS will compute the trunking network's Satellite Switch TDMA beam interconnectivity modes and mode duration from the total traffic demand matrix. It will then reconfigure the satellite switch via the command link and send the appropriate burst assignments to each trunking station via the OW. Algorithms that minimize the number of bursts per station and/or maximize the trunking throughput efficiency of the satellite will be used.

5.3.2.2 CPS

The MCS will compute the routing assignments and corresponding scanning-beam pointing frame sequence (phase shifter commands) and dwell-times for the total CPS traffic demand. These instructions will be transmitted from the MCS to the Satellite's BPU via the command link. At the same time burst assignments will be sent by the MCS to the CPS stations via the OW. Algorithms will be used to reconfigure the routing for the most efficient use of the CPS throughput capacity. The algorithms will also take into account potential co-channel interference between pairs of the six scanning beams; that is, beams will be pointed to minimize interference due to sidelobes to the extent practicable.

5.3.3 ADAPTIVE RAIN RESPONSE

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5.3.3.1 TRUNKING

The MCS will monitor the received signal power levels and BERs at each Trunking station from signals uplinked from each of the other trunking uplink beams. It will then command the High Power Mode for the downlink transmitter(s) via the command link and for the uplink transmitter(s) via the OW. It may also grant requesting trunking stations permission to switch between Low Power and High Power modes for their uplinks based upon locally determined need. In any event the MCS will monitor the current status of the High Power Modes at both the satellite and the earth stations to determine potential interference to links not using High Power Mode(s) and to limit the number and duration of High-Power Modes in the satellite to remain within power supply constraints.

5.3.3.2 CPS

The MCS will monitor the received signal power levels and BER's at each CPS station via the OW; it may also monitor received uplink signal power levels (and BER for channels using FEC decoders) at the satellite via the telemetry link. It will then instruct appropriate CPS stations to switch to the High/Low Power Mode and/or to switch in FEC uplink encoders and/or downlink decoders via the OW. It will also command the satellite BPU to switch in FEC uplink decoders and/or downlink encoders into the appropriate channels.

**5.3.4 FREQUENCY CONTROL OF THE SATELLITE MO ORIGINAL PAGE IS
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The MCS will control the frequency of the satellite MO to $\leq 1 \times 10^{-7}$ (long term) using a "disciplined" Phase Locked Loop approach. It will transmit digital "error voltage" increments via the command link which are converted to analog corrections at the MO's PLL comparator.

5.3.5 SATELLITE SWITCH TDMA SYNCHRONIZATION

The MCS will "acquire" the satellite switch, with the aid of the "disciplined" PLL MO procedure outlined in Section 5.3.4, and transmit Reference Unique Words every frame as appropriate so that both Trunking and CPS stations can establish receive synchronization with respect to the satellite's 1 KHz frame rate.

5.3.6 SATELLITE "HOUSEKEEPING" FUNCTIONS

The following functions will be performed at the MCS:

- Maintain satellite attitude control and antenna pointing.
- Perform station-keeping maneuvers.
- Monitor the "health" of critical satellite subsystem parameters via the telemetry link. Command redundant configurations in the case of component failures.

30/20 GHz EXPERIMENTAL COMMUNICATION SYSTEMFUNCTIONAL REQUIREMENTS1.0 STATEMENT OF THE PROBLEM:

The requirements of this subtask are to identify the minimum 30/20 GHz Experimental Communication System Functional requirements capable of demonstrating the applicability of 30/20 GHz satellite systems and their necessary supporting technology to commercial services.

2.0 INTRODUCTION:

The primary purposes of the 30/20 GHz Experimental Communications Program are: A) to identify projected services that are viable candidates for 30/20 GHz communication systems; B) develop the critical technology required to facilitate use of that frequency band; and C) to design, construct, and operate an experimental satellite system that will demonstrate the technology developed and applicability of the system to commercial services, and provide the facilities to evaluate other technical and propagation factors that have an influence on system performance.

In summary, NASA's main thrust is to develop and demonstrate the technology necessary to design and implement operational 30/20 GHz systems at the time satellite service growth and market demands mandate expansion to that band. NASA's purpose is not considered to be oriented toward design and construction of

an operational system directed toward development of specific market areas.

The 30/20 GHz program objectives provided the guidelines for developing the experimental system functional requirements described in this section. Consideration is given to:

- NASA's new technology development programs
- Operational trunking/CPS system requirements
- The experiments proposed by the CWG and NASA that have been incorporated into the Experiment Planning Document.

3.0 METHODOLOGY

The 30/20 GHz experimental system functional requirements have been derived based on the following:

- Incorporation within the satellite communication subsystem of the new technology hardware being developed under the auspices of NASA.
- Incorporation of those operational system functional requirements (developed in Section VI) in the experimental system necessary to demonstrate applicability of the 30/20 GHz systems to commercial trunking and CPS services.
- Considering the Experiment Planning Document, incorporation of as many of the experiment technical features as is practical.

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4.0 GENERAL CONSIDERATIONS

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4.1 NEW TECHNOLOGY:

The new technology being developed by NASA includes:

- scanning antenna for CPS applications
- Low noise wideband receiver (30 GHz)
- Impatt Power Amplifiers
- GaAsFET Power Amplifiers
- Dual Mode TWTA's
- TDMA IF switches
- Baseband Processors

The new technology hardware is incorporated in the communications subsystem as shown on the experimental system block diagrams. The dual mode TWTA is essential to demonstrating operational system capabilities since both low and high power (10W/75W) operation is required in the trunking system, and the CPS system requires a transmitter with a minimum output power of 75 watts. The output power levels expected from the Impatt and GaAsFET amplifiers (10W) are adequate for clear weather trunking operation only and cannot provide the higher power required to meet CPS requirements and the high power required in the trunking system to provide additional adaptively controlled margin to compensate for rain attenuation on the down-links.

4.2 DEMONSTRATION SYSTEM CONSIDERATIONS

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4.2.1 GENERAL SYSTEM CONSIDERATIONS

In Section VI operational system (trunking and CPS) functional requirements were identified based on estimated accessible Ka band market share and mix that may be captured by a Western Union type common carrier. The conclusion was that 500 MBPS SS-TDMA channels are a reasonable choice for trunking and that a mix of 32 MBPS and 128 MBPS uplink channels and 256 MBPS downlink channels is a reasonable choice for CPS systems except in the case of rain zone E. To meet CPS availability requirements in rain zone E one proposed design would customize uplink transmission rates to individual CPS earth station capacities using FDM channels as required and reduce the downlink TDMA transmission rate to 64/128 MBPS. (In addition the size of the proposed CPS earth station antennas in rain zone E would be increased to 5M.)

Another alternative for improving availability is the use of the Ku band for rain zone E. This would require a satellite with Ku-band receivers and transmitters interconnected to the Ka band channels operating in the other six CONUS rain zones. Interconnectivity could also be achieved by double hopping or via an intersatellite link.

4.2.2 PERFORMANCE OBJECTIVES

Experimental system quality performance objectives are

the same as those identified for the operational system in Section VI:

- Data BER $\leq 1 \times 10^{-7}$
- Voice BER $\leq 1 \times 10^{-6}$
- Video BER $\leq 1 \times 10^{-5}$

The data BER requirement is the controlling system design criteria. Other major performance parameters (e.g. availability) will be measured as part of the experimental program with margins adjusted accordingly.

4.2.3 TRANSMISSION LINK BUDGETS

Tables V-1 through V-3, V-8, V-10, VII-1, and VII-2 give the link budgets for the trunking and CPS systems. In the CPS case for rain zone E, Tables VII-1 and VII-2 give the link budgets using a 5 M antenna to provide uplink FDM transmission at 6.3 MBPS and TDMA transmission at 16 MBPS respectively with downlink TDMA transmission at 128 MBPS.

For the 16 MBS TDMA case a 5 M system is 2.9 dB shy on margin to meet a .9990 availability requirement in rain zone E. Required performance can be met with a 7 M system. A study of alternative approaches and cost trade-offs is required for the CPS system to develop optimum designs for rain zone E.

4.2.4 SYSTEM MARGINS

Some normal operating margins to offset rain attenuation effects have been provided in the link budgets.

Table VII - 1

CPS System - Rain Zone E
 6.3 MBPS FDM UL, 128. MBPS TDMA DL
 (Clear Weather, Uncoded)

ITEM	UPLINK (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
TRANSMITTER POWER	11.7 (15W) 61.3 (5M)	10.7 (75W) 40.6	dBW
RX. ANTENNA GAIN	1.0	1.0	dB
POINTING LOSS	70.0	64.3	dBW
EIRP (WITH 2 dB LINE LOSS)	213.0	209.2	dB
FREE SPACE LOSS	0.6	0.8	dB
ATMOSPHERIC LOSS	52.7	57.4 (5M)	dB
RX. ANTENNA GAIN	1.0	1.0	dB
POINTING LOSS	2.0	2.0	dB
DIPLEXER AND LINE LOSS	32.2	29.6	dB
NOISE TEMPERATURE AT RCVR INPUT	220.6	220.6	dBW/Hz/K
BOLTZMANN'S K	102.5	107.7	dB
C/kt	68.0	81.0	dB · Hz
INFO. BIT RATE	34.5	26.7	dB
CHANNEL E_b/N_0	3.0	3.0	dB
ALLOCATED RECEIVER DEGRADATION	10.6	10.6	dB
E_b/N_0 REQUIRED	20.9	13.1	dB
CLEAR WEATHER MARGIN			

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Table VII - 2
 CPS System Rain Zone E
 16 MBPS TDMA UL, 128 MBPS DL
 (Clear Weather, Uncoded)

ITEM	UPLINK * (27.5 GHz)	DOWNLINK (17.7 GHz)	UNIT
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TRANSMITTER POWER	11.7 (15W)	18.7 (75W)	dBW
TX. ANTENNA GAIN	61.2 (5M)	40.6	dB
POINTING LOSS	1.0	1.0	dB
EIRP (WITH 2 dB LINE LOSS)	69.9	64.3	dBW
FREE SPACE LOSS	213.0	209.2	dB
ATMOSPHERIC LOSS	0.6	0.8	dB
RX. ANTENNA GAIN	52.7	57.4 (5M)	dB
POINTING LOSS	1.0	1.0	dB
DIPLEXER AND LINE LOSS	2.0	2.0	dB
NOISE TEMPERATURE AT RECV INPUT	32.2	29.6	dB
BOLTZMANN'S K	220.6	220.6	dBW/Hz/K
C/KT	102.4	107.7	dB
INFO. BIT RATE	72.0	81.0	dB · Hz
CHANNEL E_b/N_0	30.4	26.7	dB
ALLOCATED RECEIVER DEGRADATION	3.0	3.0	dB
E_b/N_0 REQUIRED	10.6	10.6	dB
CLEAR WEATHER MARGIN	16.8	13.1	dB

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To meet trunking and CPS availability objectives of .9999 and .9990, respectively, additional system margins are required.

As discussed in Section V, in the case of the trunking system adaptive power control on the uplink and downlink, and space diversity earth stations at each trunking node, will provide the additional margins required. In the case of the CPS system (with the exception of Rain Zone E) adaptive uplink power control and adaptive uplink and downlink FEC will be adequate to provide the additional margins required. In the case of rain zone E, a larger earth station antenna and operation at reduced transmission data rates are required.

4.2.5 TDMA SYNCHRONIZATION

In Section V-5 and 5-3, three TDMA synchronization approaches, two closed loop and one open loop, were identified. The open loop approach is similar to that proposed by TRW, but with less stringent accuracy and update frequency. Since the number of earth stations is limited in the demonstration system, a highly precise approach which maximizes TDMA frame efficiency, such as that recommended by TRW, is not necessary. The recommendation is to implement the demonstration TDMA system using the open loop approach identified in the operational systems functional requirements.

4.2.6 TRUNKING - CPS CROSS CONNECTIVITY

An investigation of the technical and cost trade-offs of providing cross connectivity between CPS and trunk-

ing systems on-board the satellite or simply adding CPS capabilities in the trunking earth stations is recommended. Since there are a limited number of trunking earth stations the latter approach may be preferable. Switching can be incorporated at trunking earth stations to route CPS traffic through trunking channels where the terminating node is another trunking earth station or through a CPS channel where the terminating node is a CPS earth station.

4.2.7 FREQUENCY PLAN

The frequency plan for the demonstration system should include orthogonal polarized transmission of a common channel to conduct frequency reuse and depolarization experiments. The experiments should be conducted in both the trunking and CPS cases.

4.3 DEMONSTRATION SYSTEM FUNCTIONAL REQUIREMENTS

4.3.1 TRUNKING - SATELLITE COMMUNICATIONS SUBSYSTEM

4.3.1.1 TRANSMISSION REQUIREMENTS

- . SS-TDMA 500 MBPS
- . FDM 274 MBPS (T-4)
- . NTSC color video-analog 36 MHz BW

4.3.1.2 NUMBER OF BEAMS

At least seven .3° beams are required to demonstrate technology, system performance, and to conduct propagation related experiments in all CONUS rain zones.

Candidate beam cities are:

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<u>Rain Zone</u>	<u>City</u>
B	Denver
C	San Francisco or Seattle
D ₁	Cleveland
D ₂	New York
D ₃	Memphis
E	Tampa
F	Los Angeles

At least one beam should be steerable to conduct interbeam interference and frequency reuse experiments, preferable in heavy rain zone areas (e.g. Memphis beam steerable to Tampa). At least these two beams should be designed for orthogonally polarized transmission. System design should clearly demonstrate approach, requirements, and cost to provide full connectivity between twenty or more trunking nodes.

4.3.1.3 CONNECTIVITY

TDMA - Full connectivity between all seven beams is not essential, but they should be capable of being interconnected in groups of at least four.

FDM - Connectivity between beam pairs, preferably beams directed to high rain zone areas.

Video - Connectivity between beam pairs.

4.3.1.4 SWITCHING

TDMA SWITCH - An on-board TDMA switch is required to provide connectivity between beams. Switching modes and mode lengths should be reconfigurable on command.

from the MCS. Mode changes should be synchronized to avoid loss of data in the experimental network.

FDM - Switch: FDM switching is required to connect selected beam pairs. FDM experiments need not be conducted simultaneously with TDMA or video experiments, therefore common transponder(s) can be used to conduct TDMA, FDM, and video experiments. The FDM switch should be capable of bypassing the TDMA switch.

Video - For video experiments the FDM switch can be used to bypass the TDMA switch and provide connectivity between selected beam pairs. Selection of the FDM or video transmission mode can be accomplished at the earth stations.

4.3.1.5 TRANSPONDERS

At least six transponders are required, four on-line and two back-up. In addition at least one Impatt and one GaAsFET Amplifier should be incorporated in the design. The frequency plan should include adjacent frequency assignments to permit interchannel interference evaluation experiments.

4.3.1.5.1 TRANSPOUNDER POWER

A Dual mode TWTA is required:

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Low Power mode - nominally 10 watts

High Power mode - minimum 75 watts

4.3.1.5.2 TRANSPOUNDER BANDWIDTH

TDMA - The bandwidth should be compatible with the burst rate, nominally 315 MHz for 500 MBPS burst rate

(1.25 x symbol rate for QPSK modulation).

FDM - Nominally 175 MHz for 274 MBPS transmission data rate (1.25 x symbol rate for QPSK modulation).

Video - The bandwidth should be 36 MHz for NTSC color video.

4.3.1.6 SATELLITE EIRP

TDMA - Low Power Mode: 58.2 dBw min.

High Power Mode: 66.95 dBw min.

FDM - High Power Mode: 12.75 dBw/carrier

Video - High Power Mode: 12.75 dBw/carrier

Note: The Video EIRP is based on 53 dB SNR with a 4.75 dB margin. Since SNR can degrade to about 45 dB before noticeable impulse noise occurs, the effective margin is about 12.75 dB. Diversity gain can provide additional margin to maintain performance.

4.3.1.7 SATELLITE G/T

Objective: 21.4 dB/ $^{\circ}$ K

4.3.1.8 ANTENNA POINTING

Station keeping pointing accuracy should be compatible with the beamwidths to maintain synchronization and the communication link's performance even during station keeping manoeuvres. A monopulse tracking receiver will be needed to track pilot carrier frequency normally, and provide programmed tracking corrections to maintain pointing accuracy during station keeping maneuvers.

4.3.1.9 ON-BOARD MONITOR

Monitors for uplink power control may be incorporated in satellite or at earth stations.

4.3.1.10 SATELLITE COMMUNICATION SUBSYSTEM

Figure VII-1 shows a functional block diagram of the satellite trunking communication subsystem.

4.3.2 TRUNKING - EARTH STATIONS

4.3.2.1 SPACE DIVERSITY

Space diversity earth stations are required at each trunking node to meet availability objectives.

4.3.2.2 TRANSMISSION MODES

TDMA - 500 MBPS TDMA using QPSK Modulation all earth stations.

. FDM - Up to two 274 MBPS FDM channels using QPSK Modulation at selected earth stations.

Video - One 36 MHz analog video channel at selected earth stations.

4.3.2.3 ANTENNA

4.3.2.3.1 DIAMETER: 5.0 meter

4.3.2.3.2 POLARIZATION

Dual linear polarization feeds at two trunking node systems. (Tampa being one of them). Single polarization elsewhere.

4.3.2.3.3 TRACKING

Step tracked.

4.3.2.4 HPA POWER

450 Watt minimum flange power.

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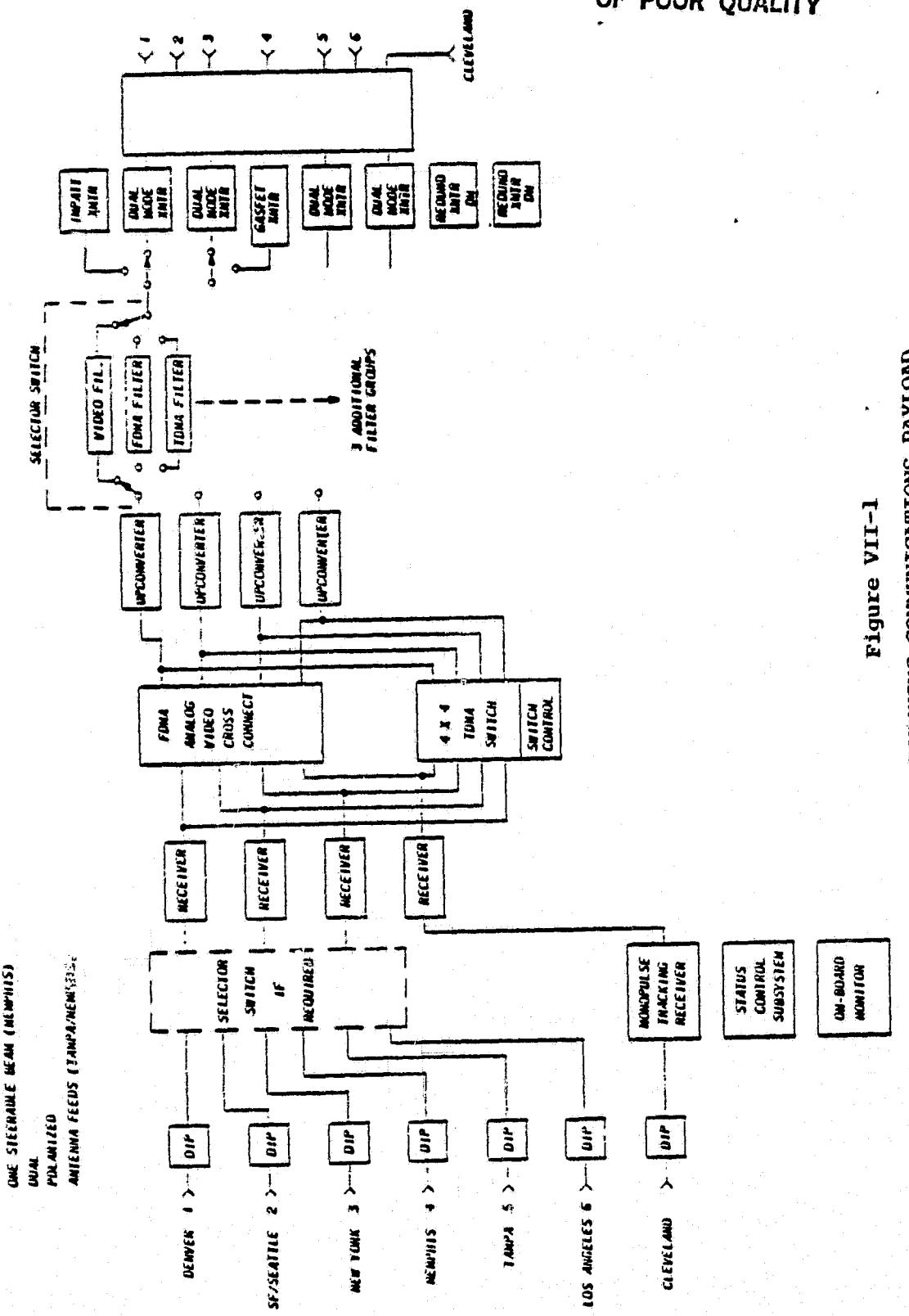


Figure VII-1

**TRUNKING COMMUNICATIONS PAYLOAD
FUNCTIONAL BLOCK DIAGRAM
DEMONSTRATION SYSTEM**

LEGEND:

DIP - DIPLEXER	DM - DUAL MODE
MMR - TRANSMITTER	

4.3.2.5 HPA POWER CONTROL

15 watt to 450 watt

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4.3.2.6 DIVERSITY SWITCH

A diversity switch is required. Transmission between diversity earth stations should be at transmission data rates (500 MBPS TDMA, 274 MBPS FDM).

4.3.2.7 DIVERSITY EARTH STATIONS INTERCONNECT LINK

Fiber Optic repeaters spaced approximately 2 KM apart.
Mux/Demux at switch (one site) only.

Note: This assumes availability of hardware at the 500 Mbps rate. Alternatively, the signals can be broken down and assembled at each station and transmitted using parallel 44.7 MBPS links.

4.3.2.8 FAULT MONITOR AND CONTROL

Status and alarm outputs interfaced to OW channel for transmission to MCS. Control inputs interfaced to OW channel from MCS.

4.3.2.9 INSTRUMENTATION

In accordance with test and experiment requirements.

4.3.2.10 INTERSTATION COMMUNICATION

Via an OW channel.

4.3.2.11 ADAPTIVE CONTROL MONITORS

Monitors with appropriate logic to identify the need for adaptive uplink power control should be incorporated in the earth stations.

4.3.2.12 TDMA SYNCHRONIZATION

Open loop approach using ranging data from master

ranging stations via OW channel.

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4.3.2.13 BASEBAND INTERFACES

TDMA/TDM - T-1 interface ports at Terrestrial Interface Modules.

Video - Picture Video 1.0 V p-p; Audio +8dBm/600 ohms

4.3.2.14 REDUNDANCY - Non-redundant equipment only for demonstration system. Consider diversity stations as backup for each other for equipment failure as well as propagation problems.

4.3.2.15 SATELLITE COMMUNICATION SUBSYSTEM

Figure VII-2 shows a functional block diagram of the satellite CPS communication subsystem.

4.3.3 CPS - SATELLITE COMMUNICATION SUBSYSTEM

4.3.3.1 TRANSMISSION REQUIREMENTS

- UPLINK: 32/128 MBPS QPSK TDMA - All rain zones
except E

6.3/12.6 MBPS QPSK-FDM Rain Zone E

- DOWLINK: 256 MBPS QPSK TDMA - All rain zones
except E

128 MBPS TDMA - Rain Zone E

4.3.3.2 COVERAGE

The demonstration system should have both scanning beam and contiguous fixed beam coverage to provide the capability to make comprehensive comparisons between the two approaches. Concerns with scanning beam systems include capacity limitations, scanning losses, synchronization complexity, gain contour slope

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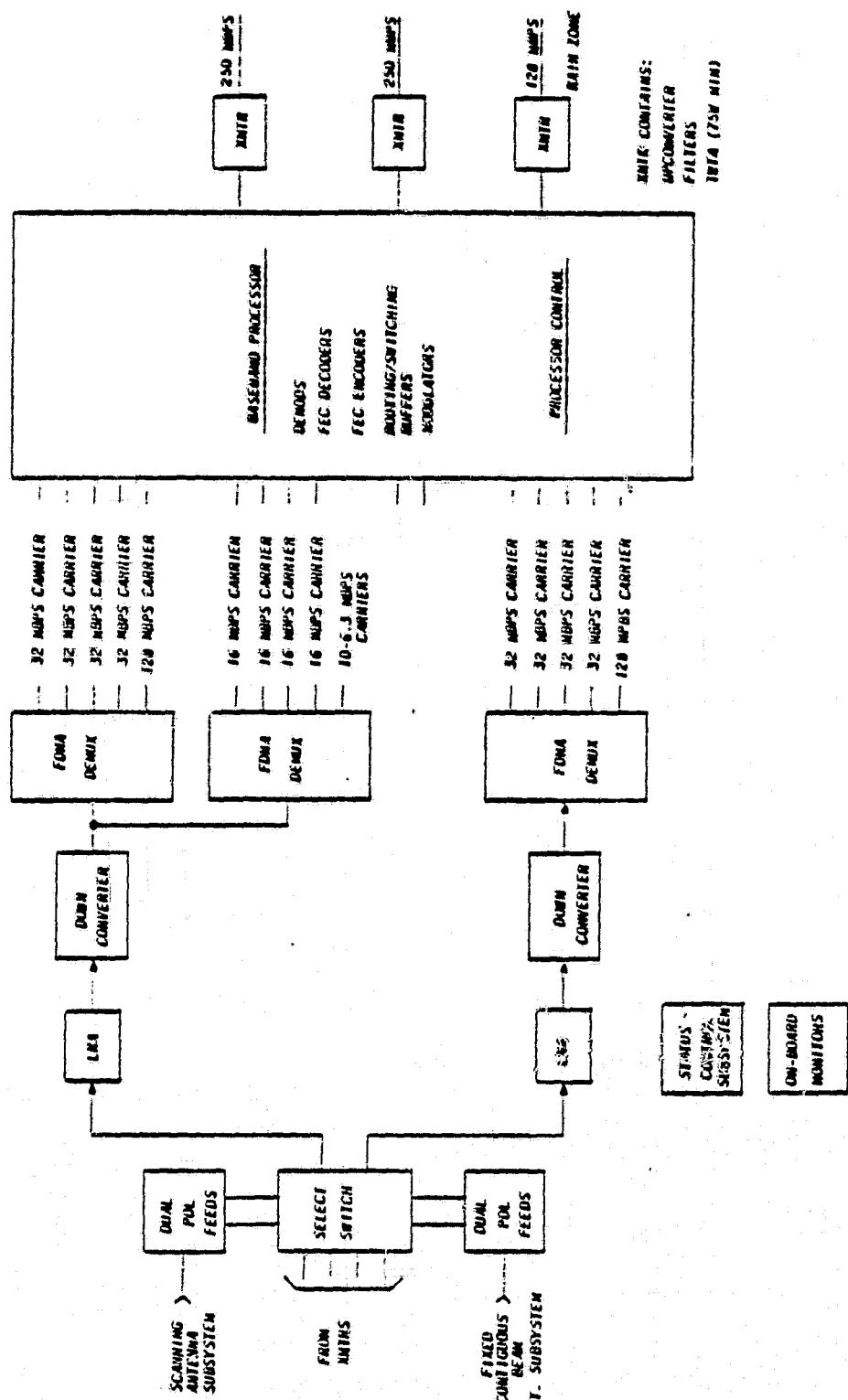


Figure VII-2 CPL COMMUNICATIONS PAYLOAD FUNCTIONAL BLOCK DIAGRAM

effects, etc. Concerns with contiguous spot beams include switching and hardware complexity. The CPS feed(s) should be designed to demonstrate and provide for analysis of frequency reuse and depolarization effects using orthogonally polarized transmission within each beam and adjacent beams. Frequency reuse via beam separation should also be demonstrated. Full CONUS coverage is desirable in the demonstration system.

If CONUS coverage cannot be implemented in the demonstration system the detailed design plan should clearly identify the design approach, performance, and cost to extend the coverage as well as the design approach for frequency reuse and implementation of at least ten CPS transponder on each satellite.

4.3.3.3 CONNECTIVITY

The CPS System is expected to be comprised of a large number of individual networks (corporate, institutional, government, carrier, etc.), in which connectivity between user network nodes is provided via wired or permanently assigned channels. In addition there will also be a pool of Demand Assigned Multiple Access channels to provide service to customers on a call-by-call basis.

On board routing for the individual user networks can be essentially fixed in the basband processor instructions and would normally require only occasion-

al reassignment as a customer expands his network, terminates services, or as a new customer enters the CPS System. A user may, however, have a need to cross connect to other user networks or may require access to DAMA channels to accommodate an overload condition on his network.

In the case of DAMA channels the requirement is to cross connect or route any input channel to any output channel.

Under the assumption that 70% of the CPS capacity will be utilized by user networks with fixed connectivity requiring occasional reassessments, and that 30% of the capacity will be utilized on a DAMA basis, the amount of real time processing is substantially reduced.

4.3.3.4 BASEBAND PROCESSOR UNIT (BPU)

The Baseband Processor Unit (BPU) will provide the capability to route any uplink message channel to any downlink message channel, irrespective of RF channels.

The BPU includes:

- Demodulators
- FEC Decoders (R 1/2, K = 7) Soft Decision Decoding)
- FEC Encoders (R 1/2, K = 7)
- Routing/Switching Buffers
- Modulators
- Processor Control

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- Uplink TDMA Expansion Buffers, Synchronization, and Control
- Downlink TDMA compression buffers, high speed mux, synchronization, framing, and control.

4.3.3.5 CPS - RECEIVE SUBSYSTEM

UPLINK CARRIER SIZE (MBPS)	NO. OF CARRIERS	TRANSMISSION MODE	RECEIVE BANDWIDTH (MHz)
32	8	TDMA	20
128	2	TDMA	80
16	4	TDMA	10 (Rain Zone E)
6.3	10	FDM/TDM	4 (Rain Zone E)

Uplink Modulation - QPSK

Bandwidth = 1.25 X symbol rate

4.3.3.6 CPS - TRANSMIT SUBSYSTEM

DLINK CARRIER SIZE (MBPS)	NO. OF CARRIERS	TRANSMISSION MODE	TRANSMIT BANDWIDTH (MHz)
256	2	TDMA	160
128	1	TDMA	80 (Rain Zone E)

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4.3.3.7 DOWNLINK TWTA POWER (FLANGE)

18.75 dBw (75W) minimum all carriers. Single mode.

4.3.3.8 SATELLITE EIRP

64.3 dBw per channel minimum - all carriers.

4.3.3.9 SATELLITE G/T

Objective 20.5 dB/K

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4.3.3.10 ON-BOARD ADAPTION MONITOR/CONTROL

Appropriate status outputs and summary alarms transmitted via the TT&C channel to the MCS are required.

Communications subsystems switching and control received via command channel from MCS.

4.3.4 CPS -EARTH STATIONS

4.3.4.1 TRANSMISSION REQUIREMENTS:

- UPLINK

32/128 MBPS TDMA Carriers

16 MBPS TDMA Carriers (Rain Zone E)

6.3MBPS FDM/TDM Carriers (Rain Zone E)

-- DOWNLINK

256MBPS TDMA Carriers

128MBPS TDMA Carriers (Rain Zone E)

4.3.4.2 ANTENNA:

4.3.4.2.1 DIAMETER:

3.5 Meter - Rain Zones B, C, D₁, D₂, D₃, F

5.0 Meter - Rain Zone E

4.3.4.2.2 POLARIZATION

Orthogonal linear polarization to provide for frequency reuse and depolarization experiments within a common beam and between adjacent beams.

4.3.4.2.3 TRACKING

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Step track.

4.3.4.2.4 G/T

$\geq 23\text{dB}/^{\circ}\text{K}$: 3.5M system $\geq 27\text{dB}/^{\circ}\text{K}$: 5.0M system

4.3.4.3 HPA POWER

450 Watt minimum flange power

4.3.4.4 HPA POWER CONTROL

Adaptive-15 watts to 450 watts

4.3.4.5 FAULT MONITOR AND CONTROL

Status and alarm outputs interfaced to OW channel for transmission to MCS. Control inputs interfaced to OW channel from MCS.

4.3.4.6 INSTRUMENTATION:

In accordance with test and experiment requirements.

4.3.4.7 INTERSTATION COMMUNICATION

OW to MCS only. Individual network interstation communications via designated voice OW channel.

4.3.4.8 ADAPTIVE MONITOR/CONTROL

Downlink BER/Carrier level monitors for control of adaptive downlink FEC via MCS.

Control to initiate adaptive uplink power and uplink FEC upon command from the MCS.

4.3.4.9 TDMA SYNCHRONIZATION

Open loop as described for trunking system. A detailed investigation/analysis is required to establish synchronization requirements and system performance with scanning beam and fixed contiguous beam systems.

4.3.4.10 INTERFACES

64 KBPS to 1.544 MBPS customer/terrestrial interfaces.

A mixture of interface port rates selected for each CPS earth test for demonstration.

4.3.4.11 REDUNDANCY

Redundancy only as required to meet CPS availability criteria. On shelf spares at depot locations.

4.4 MASTER CONTROL STATION

All of the demonstration system spacecraft monitor/control functions and the communications network control functions are centralized at the Master Control Station (MCS).

4.4.1 COMMUNICATIONS NETWORK CONTROL FUNCTIONS

4.4.1.1 SYSTEM TDMA SYNCHRONIZATION

The open loop synchronization approach described in Section V and Section VI is recommended for the demonstration.

4.4.1.2 CONTROL SPACECRAFT MASTER OSCILLATOR (MO)

Frequency lock spacecraft MO to MCS master oscillator via disciplined PLL control loop as discussed in Section VI.

4.4.1.3 CHANNEL ASSIGNMENT/ROUTING CONTROL

The channel assignment/routing control unit is the central control center for channel assignments and message routing. It performs:

- Pre-programmed assignment of fixed channels, burst slots, and routing by manual entry.

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- Determination of SS-TDMA switch interconnectivity mode lengths based on trunking earth station capacity requirements.
- Stored program control for CPS Baseband Processor.
- Reconfiguration of burst lengths or assignment of additional burst slots to accommodate FEC rain-response requirements.
- Computation of optimum scan pattern for the CPS scanning beam approach and generation of the required phase shift control commands.

4.4.1.4 ADAPTIVE RAIN RESPONSE

Central command and control point for:

- Uplink and downlink power control for trunking network.
- Control of CPS UL and DL FEC separately for each earth station link.
- Uplink power control for CPS.

4.4.1.5 EARTH STATION MONITOR/CONTROL

Remote monitoring of trunking/CPS earth station status. Remote control of critical earth station functions.

4.4.1.6 SPACECRAFT MONITOR/CONTROL

- PCF for spacecraft antenna pointing control.
- Computation of spacecraft range, range rate (state vectors).

- SS-TDMA Switch Mode Control
- Orbit Control
- Attitude Control
- Power Control
- Thermal Control
- Solar Control
- Events Control
- Switching (redundancy, configuration,etc.)
- Maintenance

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4.5 SYSTEM INTERFACES

4.5.1 TRUNKING NETWORK

- Voice orderwire channel between trunking earth stations.
- Customer baseband interfaces.
- OW channel between trunking earth stations and MCS for:
 - Voice communication
 - Earth stations - status/control
 - TDMA synchronization/burst assignments.
 - Adaptive rain response monitor/control

4.5.2 CPS SYSTEM

- OW channel between CPS earth stations and MCS for:
 - Voice communication*
 - Earth station status/control
 - Synchronization
 - Adaptive rain response monitor/control

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4.5.3 MCS AND SPACECRAFT

- Channel/burst assignments.
- TT&C and wideband channels for:
 - Spacecraft status (Telemetry/Tracking)
 - Spacecraft command and control
 - Trunking SS-TDMA switch mode control and beam switching
 - Routing/switching control and status of CPS baseband swtich.
 - CPS scanning beam control
 - Adaptive rain response monitor/control.

4.6 DEMONSTRATION SYSTEM EXPERIMENT CAPABILITIES:

The functional requirements outlined in the preceding subsections will provide transmission system capabilities to conduct most of the service, technology, and combined service/technology experiments in the Experiments Planning Document.

Key experiments are those that are propagation related, particularly measurement of diversity gain in high rain climate regions where single site attenuation substantially exceeds 20 dB.

The proposed experiments that can be conducted with addition of appropriate instrumentation and terminal facilities are:

- Service Experiments

PS-1, PS-2, PS-3, PS-8, PS-9, PS-10, PS-11,
PS-12, PS-13, PS-14, PS-15, PS-16, PS-24,
PS-25, PS-26, PS-27, PS-28, PS-29, PS-30,
PS-31, PS-32, PS-33, PS-34.

In the case of PS-10 the terrestrial interface must be designed to be compatible with the fiber optic link, T-3 interface probably. Experiments PS-28, PS-30, and PS-34 are experiments that require carrier participation.

- Technology Experiments

PT-1, PT-2, PT-3, PT-4, PT-5, PT-7, PT-9, PT-10, PT-15, PT-16, PT-18, PT-19, PT-20, PT-21, PT-23, PT-24, PT-25, PT-28.

- Service and Technology Experiments

PSAT-3, PSAT-4, PSAT-5, PSAT-6, PSAT-8, PSAT-9.

The proposed experiments that cannot be conducted with the demonstration system described are:

- PSAT-1, PSAT-2, PSAT-7, PSAT-11

The special capabilities required for these experiments are not incorporated in the functional requirements identified.

- PT-6, PT-14, PT-17, PT-22

These experiments require an intersatellite link that has not yet been identified as a 30/20 GHz program requirement.

- PT-12

FEC has not been incorporated in the functional requirements as identified pending more specific requirements.

PT-13

Recommendations via the proposed experiment pending NASA review.

PS-4

Beyond scope of 30/20 GHZ program. Additional hardware required.

PS-17

Trunking stations are diversity facilities. Diversity experiment as described can be implemented with a transportable earth station in conjunction with NYC facilities.

PS-18, PS-19, PS-20, PS-21, PS-22

Can be accomplished by simulations.

PS-23

"C" band capabilities not being considered because of the saturated status of available "C" band orbital slots.

5.0 30/20 GHZ DEMONSTRATION SYSTEM FUNCTIONAL PRIORITIES

5.1 GENERAL: The demonstration system functional requirements defined in the preceding sections are those considered necessary for demonstrating the applicability of a 30/20 GHZ satellite communication system to projected trunking and CPS carrier needs and services.

In the on-going Phase II study efforts the study contractors have developed baseline and alternate demonstration system design concepts. These identify the range of capabilities that might be developed and implemented in flight systems with various size launch vehicles (SUSS-D, SUSS-A, etc) and develop program cost projections for various required system capabilities. The demonstration system functional requirements and study contractor design concepts have been reviewed to rank the 30/20 GHZ technology and capabilities considered essential for demonstrating a 30/20 GHZ system for trunking and CPS carrier service applications in order of importance.

5.2 MODULATION TYPES

In Section II of this report three types of carriers were identified; trunking only carriers, CPS only carriers, and carriers providing both trunking and CPS services. To meet the needs of the three types of carriers the demonstration system must provide both trunking and CPS capabilities.

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In the trunking case three types of transmission capabilities have been identified; TDMA, FDMA, and analog video. From a carrier point of view TDMA is the preferred transmission approach because it is more efficient and has greater flexibility than FDMA. The relative order of importance is, therefore, TDMA, FDMA, and analog video. The latter has been included in the functional requirements not as a trunking alternative, but to verify performance capabilities in the 30/20 GHZ band for video service application.

In the case of CPS demonstration system capabilities the size of the potential aggregate of use networks and relatively large number of earth stations mandates that they be low cost, with only a level of redundancy adequate to meet CPS availability criteria. There are propagation (rain attenuation) problems associated with the CPS system concept that will probably result in customizing uplink/downlink channels and transmission rates to satisfy availability criteria. Consequently, both TDMA and FDMA transmission capabilities should be demonstrated.

5.3 SATELLITE ANTENNAS

The CPS system will be comprised of a large number of individual user networks with network nodes that can be located throughout the CONUS area. Demonstration of the CPS system's capability to provide CONUS coverage through the use of scanning beams and contiguous

beams is necessary, since there exists a fair level of concern relative to the performance capabilities of both approaches. In view of this performance uncertainty it is desirable to implement both types of antenna systems on the demonstration flight to evaluate their relative performance capabilities and to develop the necessary synchronization techniques required for system operation.

5.4 SATELLITE SIGNAL PROCESSING CAPABILITIES

A demonstration of solutions to the availability problems require that the CPS communication subsystem be implemented with high power amplifiers and adaptive FEC decoders and encoders.

The baseband processor is the heart of the CPS system and must be demonstrated. The ability to support fixed assignment and demand assignment channels and routing under both average and peak hour loading conditions should be demonstrated. Demonstrations of CPS/Trunking cross connectivity can be provided for either in the satellite subsystems or on the ground.

5.5 TECHNOLOGY DEVELOPMENT

The technology development efforts applicable to the trunking systems are:

1. 30 GHZ Low Noise Amplifier
2. IF Switch
3. Impatt Amplifier
4. GaASFET Amplifier
5. Dual Mode TWTA.

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Items 3 and 4 are not likely to be available at required power levels to satisfy trunking system availability criteria in time for the demonstration system. The emphasis, therefore, should be on items 1, 2, and 5 for demonstration system implementation. Development programs for items 3 and 4 should be conducted on an on-going basis to develop amplifiers capable of operation at high power levels $\geq 75W$, a substantial extension beyond the present design objective. Because of the power limitations of the solid state amplifiers currently being developed, implementation of these devices in the demonstration system will not be useful. They will also not be essential to demonstrate trunking system capabilities for an initial operation Ka-band system since this can be done with the high power TWT's under development.

5.6 PROPAGATION EXPERIMENT CAPABILITIES

Measurement of propagation characteristics in the 30/20 GHZ band is necessary to develop propagation models for use in the design of operational systems, for example, available diversity gain during deep fades, and to analyze propagation effects on the performance of wideband data transmission system.

5.7 SUMMARY

In summary, the demonstration system must as a minimum include those features defined for the TDMA trunking and CPS systems in preceding sections. In general

the demonstration system should provide the capability to conduct the systems operational/performance, propagation, beam characteristics, interbeam interference, synchronization, and frequency reuse experiments recommended by the carriers. Trunking FDMA and analog video capabilities are also of value but these may be assigned a lower priority.

VIII

ADDITIONAL STUDY RECOMMENDATIONS

There are several areas that can have considerable influence on the performance capabilities, technical design, and cost of both the demonstration and subsequent operational systems that require additional study efforts.

1.0 Rain Zone E Alternate Design Approaches

Rain attenuation and the related margin required to meet the .9990 availability criteria for the GPS system has been shown to be a problem in the CONUS rain climate zone E. One alternative design approach to satisfy performance and availability requirements has been discussed. In that approach the GPS antenna size for earth stations in rain zone E was increased to at least 5.0M and transmission data rates were substantially reduced. A second approach using intersatellite links to a lower frequency band for rain zone E coverage was also identified. The basic premise of the CPS system is that it is intended to provide low cost direct to user services. Inefficient use of the space segment and increased ground segment costs lead to increased user service costs.

A study to identify alternate design approaches is required so that the system design implemented results in the minimum service cost of GPS users.

2.0 CPS Traffic Mix

The CPS system is planned to be implemented with an on-board Baseband Processor Unit to route traffic between assigned uplink and downlink channels. The central control of the BPU resides in a computer at the MCS. Machine size and processing requirements can vary considerably as a function of the number of circuit connections required on a message-by-message demand basis. At one extreme is the case where all channels are assigned on a DAMA basis and routing is required on a message-by-message basis. At the other extreme is the case where all channels and hence BPU connectivity is permanently or fixed assigned. The first case requires a computer with substantially more processing capabilities than the second. The real case is somewhere in-between.

A study is necessary to identify the probable CPS mix, i.e. ratio of fixed assigned to demand assigned channels, to appropriately size the machine and processing required.

3.0 TDMA Synchronization Approaches

A study is required to identify TDMA synchronization approaches and the performance/cost trade-offs between them. TDMA synchronization approaches vary widely in terms of their respective performance capabilities and cost, however, the ultimate design selected should be established on a total systems basis that considers:

- Cost and complexity of the synchronization approach.
- The impact on cost and complexity in other areas of the system as a function of the synchronization approaches.
- The impact on throughput efficiency and space segment cost.
- Total system size (i.e. number of earth stations) it is desirable to select an approach that minimizes initial implementation cost, but one that can be gracefully expanded to improve system efficiency as the network size increases and additional capital costs can be more easily justified.

4.0 SCANNING BEAM/FIXED CONTIGUOUS BEAM DESIGN AND PERFORMANCE:

There are enough concerns relative to capacity constraints, performance, complexity, synchronization, and cost of scanning beams that an in-depth design study is recommended to investigate both scanning beam and fixed contiguous beam approaches for the CPS system. The CPS system is only marginally capable of meeting established availability criteria and, as shown previously, cannot meet availability requirements in rain zone E without other system design changes. Additional losses will have further impact on system performance capabilities.

IX INTERSATELLITE LINKS

1.0

INTRODUCTION

Rain attenuation varies appreciably as a function of earth station elevation look angle (as shown in Figure IV-3) and, therefore, high elevation look angles are desirable (30° or greater). Elevation angle contours were shown in Figures IV-4 and IV-5 for satellites stationed at 90°N and 97°W Longitude. The elevation angle contour plots show that the preferred satellite location is 97° W and that the usable domestic arc for Ka band systems is between 90°W and 104°W Longitude. Rain attenuation also imposes constraints on attainable transmission throughput rates in high rain zone areas, particularly in the case of the CPS system.

An intersatellite link has the potential to extend the usable orbital arc, improve transmission throughput rates and efficiency for Ka band systems, and offers other advantages when considered on an integrated system basis with other domestic and international satellites. Advantages, applications, and a cursory look at the basic intersatellite link functional requirements are given below. An intersatellite link implementation approach is identified. However, an in-depth effort is necessary to explore alternatives.

2.0 INTERSATELLITE LINK CONSIDERATIONS

Whenever the use of more than one satellite transmission hop is envisioned for a particular service category or class of user, which uses two or more different satellites, several factors should be assessed:

1. In most cases, the transmission delay is undesirable. This is particularly true for voice and interactive data applications. For other data applications such as facsimile, electronic mail, and remote batch computing, increased delay is not a fundamental problem, but increased storage is required at the sending location to permit operation with error correcting protocols.
2. The use of multiple hops requires that earth stations which do not have full connectivity via a single satellite have some means of accessing more than one satellite. This can be accomplished using multiple earth station antennas or by using a multi-beam torus antenna.
3. Multi-hop operation results in multiple use of a given bandwidth for the same channel, which results in inefficient use of frequency spectrum and orbital arc.
4. All of these effects of multi-hop transmission increase systems costs to some extent and, as such, should be minimized to the extent possible.

The use of an intersatellite link reduces these effects for some applications. The advantages and applications of intersatellite links are considered in the following sections.

2.1 ADVANTAGES OF THE INTERSATELLITE TRANSMISSION LINK

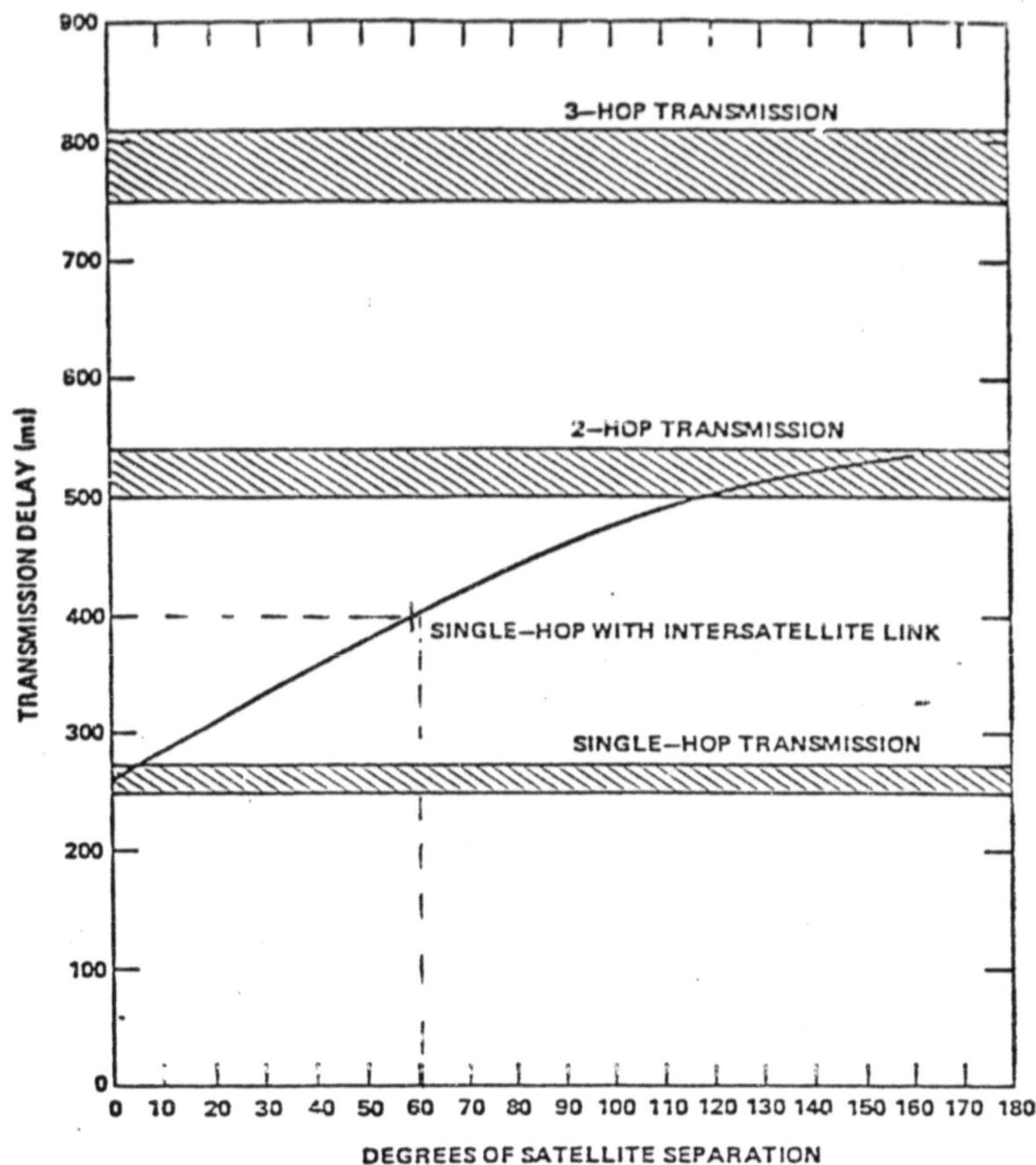
2.1.1 DELAY

For all but the very largest longitudinal satellite separations, the satellite interconnection with intersatellite links result in much lower transmission delays than the multi-hop interconnection. This is illustrated in Figure IX-1.

The maximum distance between two satellites for which a single intersatellite link can be used corresponds to an angular satellite separation of about 160° . For a larger separation the earth would obstruct the direct transmission path between two satellites. However, already at an angular satellite separation of 120° the transmission delay time over the intersatellite link approaches that of the additional delay of a double-hop circuit.

It can be concluded that the direct link connecting two satellites through an intersatellite relay is always preferable to triple-hop connection which would result from the conventional interconnection of two domestic systems with the INTELSAT System. However, the intersatellite link also offers a substantial reduction in transmission delay relative to a double-

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MULTI-HOP INTERSATELLITE LINK TRANSMISSION DELAY

FIGURE IX-1

hop connection when the angular spacing between two satellites is 60 degrees or less.

For full CONUS coverage, the maximum angular separation possible while still maintaining a minimum elevation angle of 10 degrees is about 73 degrees of longitude. Since in the 20/30 GHz fixed service satellite system the satellites are likely to be placed relatively close together and near the central portion of the possible orbital arc positions, the separation will be considerably less than 60°. Thus, use of intersatellite links in the 20/30 GHz satellite system will offer substantially decreased transmission delays relative to the use of multi-hop transmission.

2.1.2 CONSERVATION OF FREQUENCY SPECTRUM

In addition, the intersatellite link uses higher frequency bands than those presently used for satellite communications. This is possible because of the absence of atmospheric absorption and precipitation attenuation for the intersatellite links, and it is desirable because very high directivities can be achieved with moderate size antennas. These frequencies do not interfere with earth-to-satellite transmissions, and therefore the use of the intersatellite link conserves the frequency spectrum.

2.1.3 CONNECTIVITY

As the use of satellites for more and more communications needs expands, and there is overwhelming evi-

dence that this will indeed happen, the problems of connectivity will become increasingly important. It is easy to imagine a situation where a telephone call, for example, originating within a foreign domestic satellite system, is subsequently relayed to an INTELSAT satellite for transmission to the U.S., and relayed again via a domestic satellite before finally reaching its destination. In fact, even more satellite hops can be envisioned. The provision of intersatellite links on all types of communications satellites in the future can ensure that excessive delays are minimized, that valuable spectrum is used in an efficient manner, and that system costs are kept at a minimum.

3.0 POSSIBLE APPLICATIONS TO THE 20/30 GHz FIXED SATELLITE SYSTEM

Provision of full interconnectivity to all users of the 20/30 GHz system when multiple satellites are used can be accomplished through a combination of the techniques already discussed, i.e. use of multiple earth station antennas, multibeam torus antennas, and intersatellite links. In an operations system, a combination of these interconnection techniques can be expected to be used.

In the previous section dealing with elevation angle constraints, it was concluded that a minimum elevation angle of 30 degrees from an earth station to the satellite is desirable for a 30/20 GHz fixed satellite

system. The desirability of such a system geometry stems from the effect that elevation angle has on required rain attenuation margins. As elevation angles are decreased much below 30°, margins begin to become larger than can reasonably be provided by state-of-art earth station and satellite technologies. One of the solutions suggested was the use of a dual satellite system, one of which would serve the primary need of the eastern portion of the U.S. and the other of which would serve the primary need of the western portion of the U.S. The traffic which requires interconnection between East and West Coast could conveniently be handled via an intersatellite link. In addition to providing more desirable elevation angles over a greater portion of the U.S., such an implementation may lead to simpler satellites designed specifically for East or West Coast use which in turn provide additional weight and power that can be used for more sophisticated on-board processing or increased EIRP coverage, for example. Such a configuration would require that traffic patterns in East and West Coast regions, as well as between the East and West Coast regions be known with sufficient precision to allow optimized satellites to be constructed.

Hughes, in its final report, identified a case where the need for a maximum of three hops for connection of CPS traffic when any user within a fixed beam is

restricted to communicating with a master station in its own beam. The master station in turn would relay the traffic via a second satellite hop to another CPS station in the same beam. When the traffic is destined for a CPS station in another beam the traffic would first be relayed to the master station in that beam and finally, via another satellite hop, to the destination CPS station. In this latter case, the second relay of traffic could either be accomplished by terrestrial connection of master stations, in which case two hops would be involved, or via a satellite connection between master stations in which case a total of three satellite hops would be involved. The use of a two satellite configuration and intersatellite link as discussed could serve to relay traffic via intersatellite link to the second access community. The net effect of this approach would be a simpler CPS on-board processor (than one which must provide full interconnectivity to all CPS terminals on each satellite,) which would provide full connectivity between CPS terminals for a limited community of users without the need for multiple hops.

Another possible application of intersatellite links which could widen the attraction of the 20/30 GHz system would be as a relay of television signals to a CONUS coverage broadcast type satellite. This would be attractive to TV network operators who could

broadcast directly from any downtown location at Ka-band using a small, easily coordinated earth terminal. In this way, interconnect cost to remote earth stations would not be required, and an earth terminal could easily be placed on the rooftop of centrally located studios.

4.0 FUNCTIONAL REQUIREMENTS

4.1 GENERAL CONSIDERATIONS

An approach to implement a trunking system with an intersatellite link is to provide separate TDMA carriers for transmission between earth stations within the coverage area of each satellite and additional carriers for the intersatellite link.

The initial cursory functional design approach for the trunking network connectivity via an intersatellite link is similar to the previously described trunking functional requirements. A TDMA - IF switch provides the connectivity between the intersatellite link and the Ka-band trunking network. Switch mode configuration and mode length are controlled by the MCS.

In the CPS system uplink, Ka-band signals are processed and routed to the baseband processor unit and interfaced to an intersatellite channel. Conversely incoming intersatellite link traffic is processed and routed through the intersatellite link and interfaced to a Ka-band system downlink TDMA channel.

4.2 FUNCTIONAL REQUIREMENTS

4.2.1 Ka TRUNKING - INTERSATELLITE LINK CONNECTIVITY

Figure IX-2A shows a general block diagram of the Ka Trunking - Intersatellite Link satellite communications subsystem. The intersatellite link appears as an extra set of ports (input and output) on the TDMA - IF Switch. The basic additional functional requirements are:

Intersatellite Link Receiver - An intersatellite link receiver is required to amplify (low noise) and down convert received 58/59 GHz carriers that are interfaced to the TDMA - If Switch for connection to Ka trunking downlink beams.

Intersatellite Link Transmitter - An intersatellite link transmitter is required to up convert and amplify trunking TDMA carriers for transmission via the intersatellite link.

Intersatellite Antenna Subsystem - An intersatellite link antenna(s) with an appropriate number of spot beams, compatible with the number of satellites to be interconnected, is required.

4.2.2 Ka CPS - INTERSATELLITE LINK CONNECTIVITY

Figure IX-2B shows a general block diagram of a Ka CPS-Intersatellite Link Communications subsystem. The intersatellite link appears as an extra set of ports on the baseband processor. The basic additional functional requirements are:

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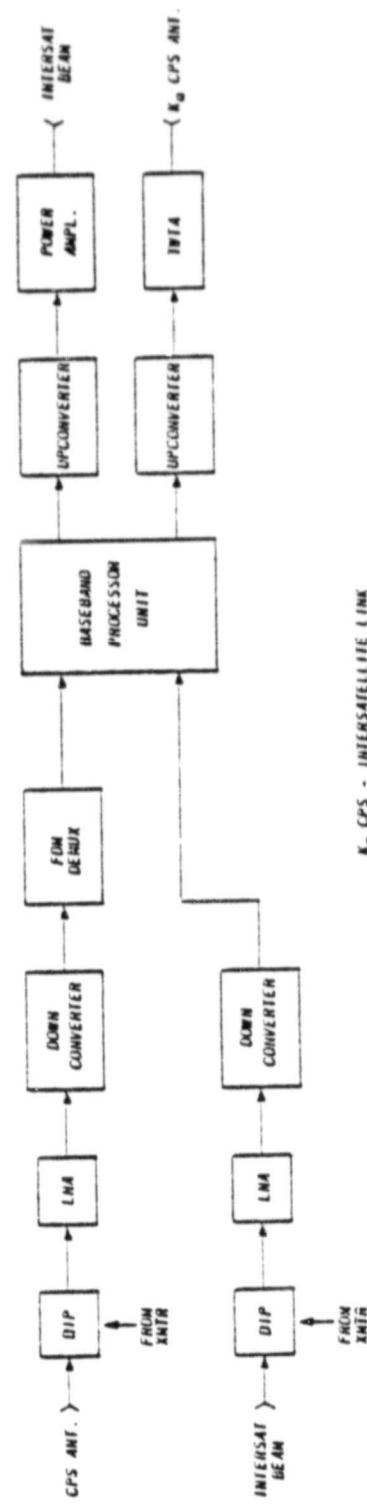
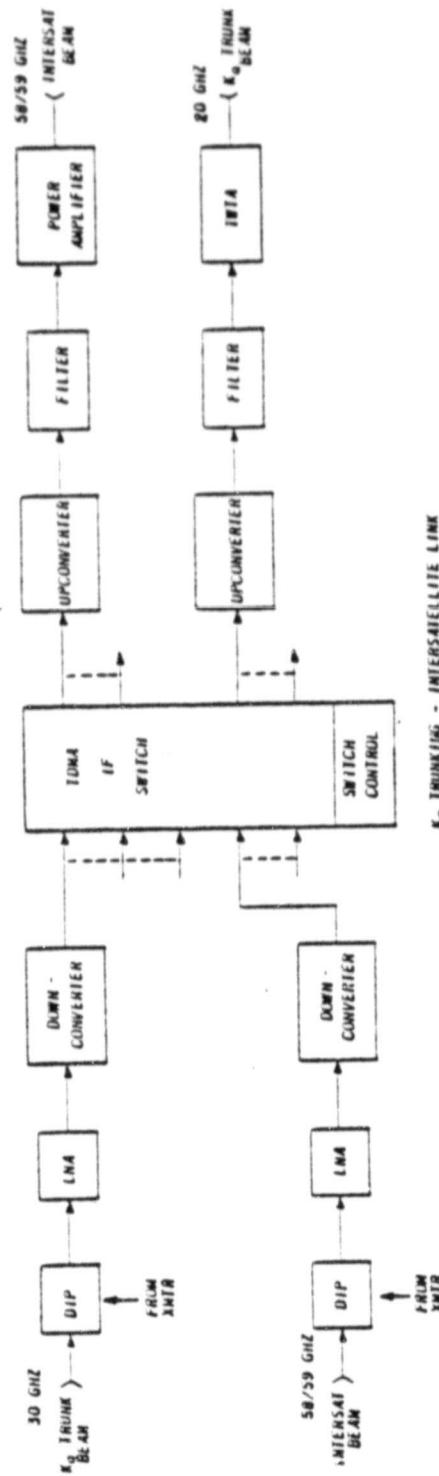


Figure IX-2
 K_a TRUNKING & CPS INTERSATELLITE LINKS
FUNCTIONAL BLOCK DIAGRAM

LEGEND:
DIP - DIPLEXER

Intersatellite Link Transmit Subsystem - A transmit subsystem is required to upconvert and amplify TDMA carriers for transmission via a 58/59 GHz intersatellite link.

Intersatellite Link Receive Subsystem - An intersatellite link receive subsystem is required to amplify (low noise) and downconvert the received 58/59 GHz TDMA carrier for application to the BPU.

Intersatellite Antenna Subsystem - The intersatellite CPS and trunking traffic will share an antenna with an appropriate number of spot beams compatible with the number of satellites to be interconnected.

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APPENDIX A
ANTENNA SPECIFICATIONS

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1.0 TYPICAL WESTERN UNION ANTENNA ENVIRONMENTAL
SPECIFICATIONS

1.1 POINTING ACCURACY

a. The pointing accuracy shall be consistent with the following gain degradation limits in the direction of the satellite under Normal Weather Conditions and for 99% of the worst month of the year.

0.3 dB in the 3.7-4.2 GHz band

0.5 dB in the 5.925-6.425 GHz band

b. Additionally, the antenna pointing accuracy shall be not worse than 0.02 degrees rms under wind velocity conditions of 45 mph, gusting to 60 mph.

1.2 ENVIRONMENTAL CONDITIONS AND CAPABILITIES

The antenna shall be designed for continuous and reliable service over a minimum 15 year life. The above requirements shall be met under the following environmental conditions, applicable to the reflector/pedestal assembly:

a. Normal Weather Condition

Wind: 30 mph (any direction), gusting to 45 mph (3 sigma)

Temperature: 0 °F to +100 °F

Humidity: 20% to 100%, relative

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Solar Radiation: 350 BTU/Ft²GR

b. Poor Weather Condition

Wind: 45 mph (any direction), gusting to
60 mph (3 sigma)

Rain: a five-minute rate of 0.5 inches

Snow: 2 In/Hr

Ice: (a) 1" Thick radial over all antenna
surfaces

(b) 1-1/2" over lower of half dish
only

Temperature: -15 °F to +100 °F

Humidity: 0% to 100%, relative

Wind & Ice: All combinations of wind &
ice

c. Extreme Conditions and Survivability

Wind (Survival): (a) 120 mph in stow
position

(b) 70 mph with 1" ice in stow position.

Temperature: -30 °F to +100 °F

Drive to Stow: 70 mph wind load (worst
direction)

Hold in Position: 80 mph wind load (worst
direction)

d. Equipment Survival in Storage and Trans-
portation

Temperature: -62 °F to +185 °F

Altitude: 40,000 Ft.

2.0

LARGE GROUND STATION ANTENNAS AT 20 - 30 GHZ

The TRW and Hughes trunking designs utilize 12 meter antennas. This is a comparatively a large antenna, even at 6 and 4 GHz, but for the 20/30 GHz range it presents many problems, the solutions to which are not all immediately obvious. Some of these problems are:

How to provide parabolic surfaces with sufficient accuracy.

How to design mounts and sub-reflector supports with adequate stiffness.

Automatic or programmed tracking.

Compensation for building sway.

Servo loop compensation.

All of the above problems are inter-related, but there is another problem not considered in lower frequency systems which may introduce perturbing inputs into the tracking system. This is the possible variation in phase across the aperture of the antenna of the arriving energy from the satellite, due to rain cells which can conceivable cause distortion of the arriving wave front, resulting in loss of signal over and above that caused by attenuation of the beam in passage.

2.1

SURFACES OF PARABOLIC DISHES

The operating efficiency of a parabolic dish, which relates actual gain to theoretical gain of an ideally

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illuminated parabola, is determined by the deviation of the dish surface from the desired contour, and by the effectiveness of the feed in achieving the ideal illumination distribution.

At these frequencies, the dish shaping tolerance is the most difficult to achieve due to manufacturing and installation problems of the dish surface and back-up structure. In addition to still air conditions, the dish surface and feed geometry must be maintained under high and gusting wind conditions, depending on locality. Typical designs call for meeting performance specifications in the following environmental conditions:

Temperature range - 0°F to +100°F

Rainfall - a five minute rain rate of 0.5
inches

Solar radiation - up to 1,000 kilo-cal/hr/M²

Wind - survival in winds up to 120 mph, move
in winds up to 70 mph

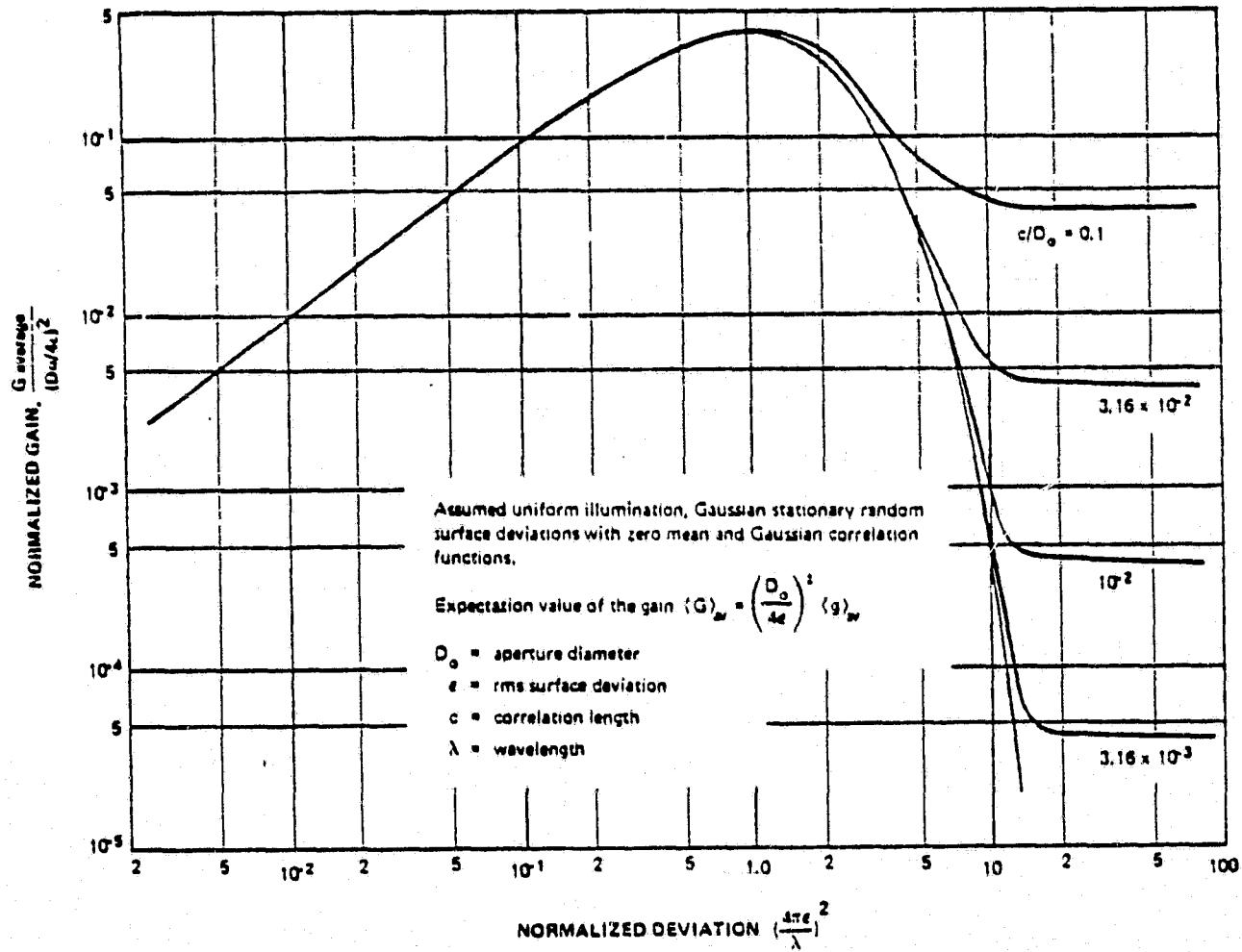
Tracking error - .0065° in winds 49 km/h
gusting to 73 km/hr, 0.1° in winds of 75 km/hr
gusting to 96 km/hr

Dish surface tolerance for any D/ is characterized by rms surface deviation and correlation interval. These factors are related to gain as illustrated in Figure A-1.

The gain loss illustrated in Figure A-1 does not in-

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Aperture Gain Loss Due to Random Errors



Reprinted from the Bell System Technical Journal, Vol. 47, No. 8, October, 1968, pg. 1643.

FIGURE A-1

clude gain loss due to high winds distorting the dish or affecting tracking accuracy. Extrapolation of costs from C or X band to arrive at a cost for a 20/30 GHz antenna is not considered a good approach.

2.2 MOUNTS AND SUB-REFLECTOR SUPPORT

The present dish structure designs are optimized for C-band and may not be suitable for 20/30 GHz, making extrapolation of costs questionable. It is likely that the dish and amount will both have to be redesigned, as well as the sub-reflector support. The closest known technologies are radio telescope antennas and solar tracking furnaces. These seems like logical places to start in predicting costs.

2.3 BUILDING SWAY

In the case of antennas mounted on the roofs of buildings more than a few stories in height, building sway can be a factor in determining the pointing angle. Monopulse tracking may not be affected in these cases, but step-track could experience a problem in certain wind conditions.

2.4 RADOME

Mention is made of the use of a radome, whose manufacturer claims that due to special surface-coating techniques, will yield a maximum alteration of 20/30 GHz of 1 dB. If this is true, it will greatly alleviate the above problems due to wind and rain loading.

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2.5

POINTING

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Antenna pointing will be a very large problem. If local pointing is used (monopulse or step-track) with great attention to design details, many of the perturbations can be minimized dynamically. This is particularly true with monopulse. With remote commanding of antenna pointing angle, the system operation depends on accurate prediction of losses due to environmental conditions and pointing command accuracy. One suggested solution is to provide a low-power beacon, operating at a lower frequency (4 GHz for example) to be used for pointing. This would ease the problem of loss of track in heavy weather at the cost of added complexity. This may not be necessary, since at least in the TRW system, there are phase-locked loops with 100 Hz bandwidth, which could possibly provide sufficient margin for step-track operation.

3.0

CURRENTLY AVAILABLE HARDWARE

Concern over the problems associated with the practicability of building both large and medium aperture antenna systems led us to look to a supplier of Radio Astronomy systems, which operate at frequencies up to 150 GHz. The problems associated with these antennas fall in the following areas:

1. Maintaining necessary surface accuracy during manufacture and assembly.

2. Maintaining surface accuracy under severe wind and rain conditions.
3. Pointing system accuracy.

We have located one viable source of suitable antennas. This is:

Electronic Space Systems Corporation
 Old Power Mill Road
 Concord, Massachusetts
 Telephone: 617-369-7200
 Contact - Samuel L. Hansel, Jr. ScD
 Sales Manager/Systems Specialist

We have received a packet of very interesting information about these antennas, which is summarized below with comments.

3.1 SURFACE ACCURACY

Surface rms error E is computed by means of the following expression:

$$E = \left[\frac{1}{n} \sum_{i=1}^{i=n} x_i^2 \right]^{1/2}$$

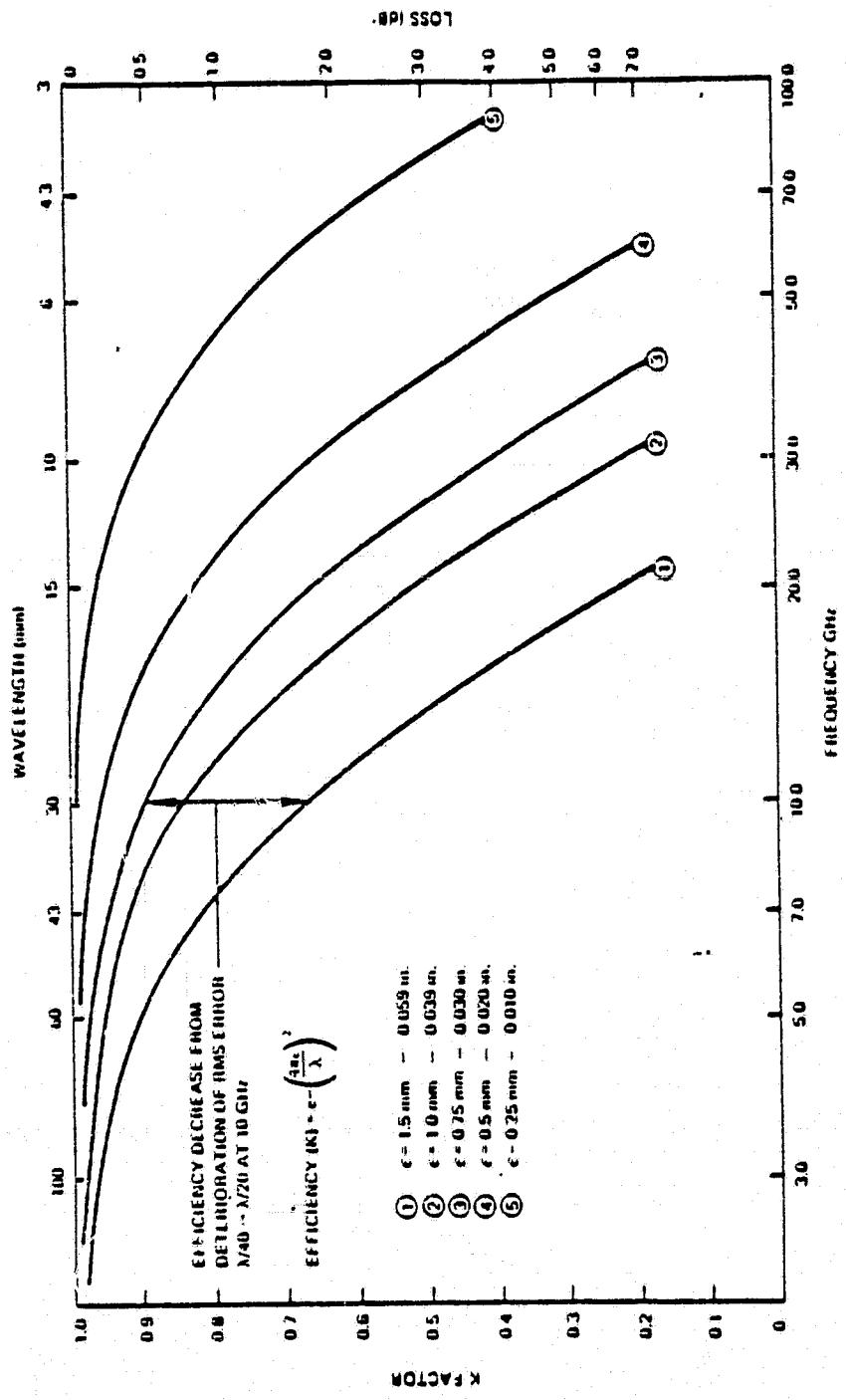
if the distribution of surface errors x_i is Gaussian.

A curve relating E to k factor (efficiency) is shown in Figure A-2. k factor is computed according to the formula

$$k = e - \left[\frac{4E}{\lambda} \right]^2$$

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EFFICIENCY (K) FACTORS AND GAIN LOSS DUE TO REFLECTION SURFACE IMPURITIES

Figure A-2

These curves are completely theoretical. Some insight into actual performance expectations can be learned from an ESSCO pamphlet on a 45 foot dish built for the University of Massachusetts. The surface of this dish consists of 2 precision aluminum panels, manufactured to a surface accuracy of about 0.06 mm. The assembled dish has an overall accuracy of 0.1 mm across the entire aperture, better than required for 30 GHz operation by a factor of about 2.

3.2 EFFECTS OF WIND AND RAIN

ESSCO provides complete systems, including the antenna (with feed system), mount, and drive system. Their antenna design is based on operation inside a special radome of proprietary design. A typical radome is pictured in Figure A-3. It consists of an aluminum space-frame. The space-frame is composed of triangular panels bolted together to form the structure. The aluminum structural elements are encapsulated in a special low-loss dielectric, and the actual surface is made up of a special membrane.

The use of the radome effectively eliminates the effect of wind, with virtually no penalty on performance, which is very surprising. It simplifies both structure and drive systems and lowers costs in these areas. Rain accumulation on the radome is virtually nil, due to the membrane material which causes rapid runoff. The noise temperature increase due to rain

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ESSCO Model M68-78 (68 ft. Diameter) Metal Space Frame Radome

Figure A-3

is quoted as less than 10°K . Another benefit is reduced maintenance, although the membrane surface does require some cleaning.

Performance of these systems is illustrated in Figures A-4 and A-5. There are theoretical curves for assumed k factors, but ESSCO asserts that actual systems attain values indicated in the curves or better.

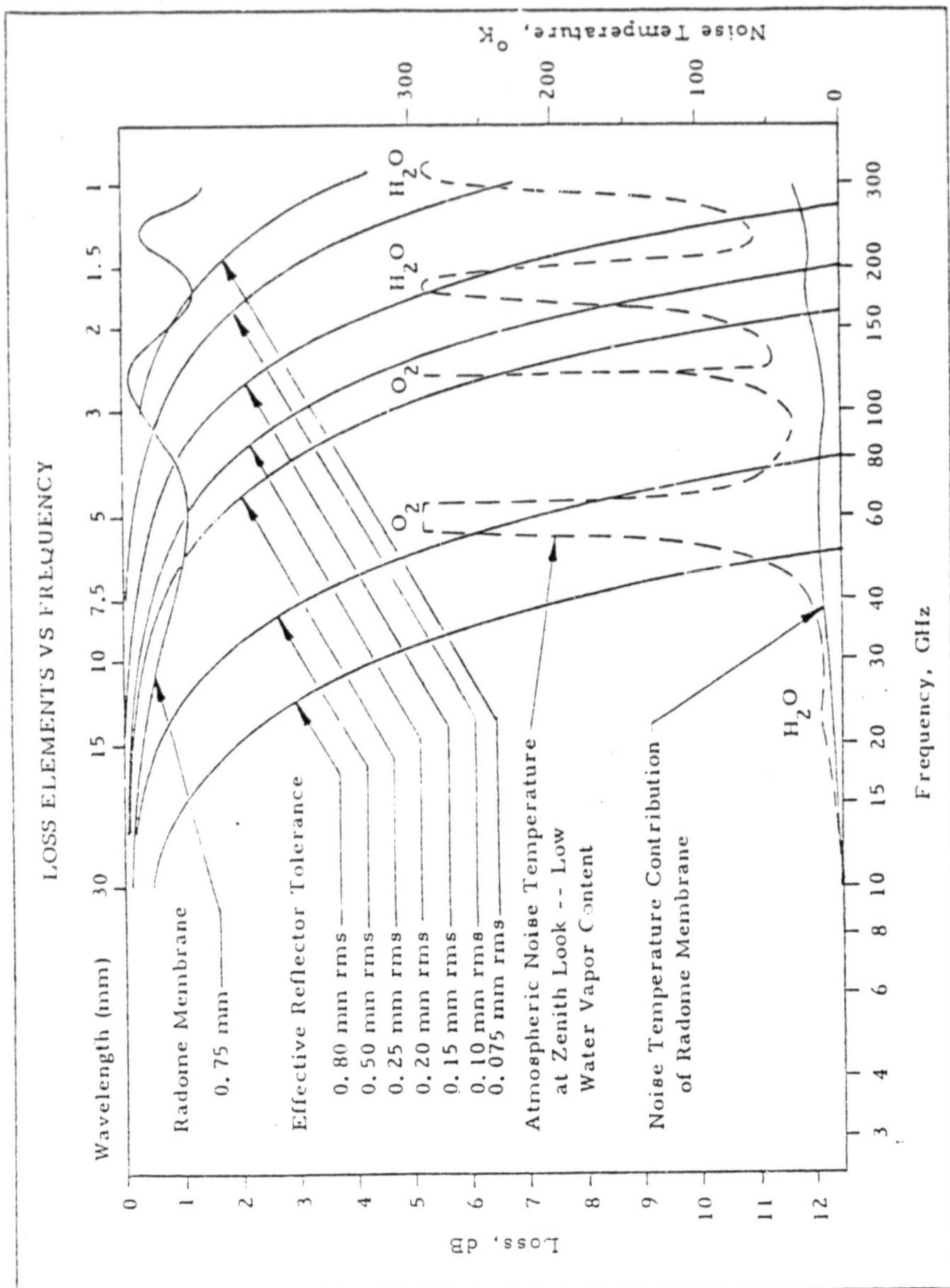
3.3 POINTING ACCURACY

Servo accuracy approaches 2 arc seconds.

3.4 COST

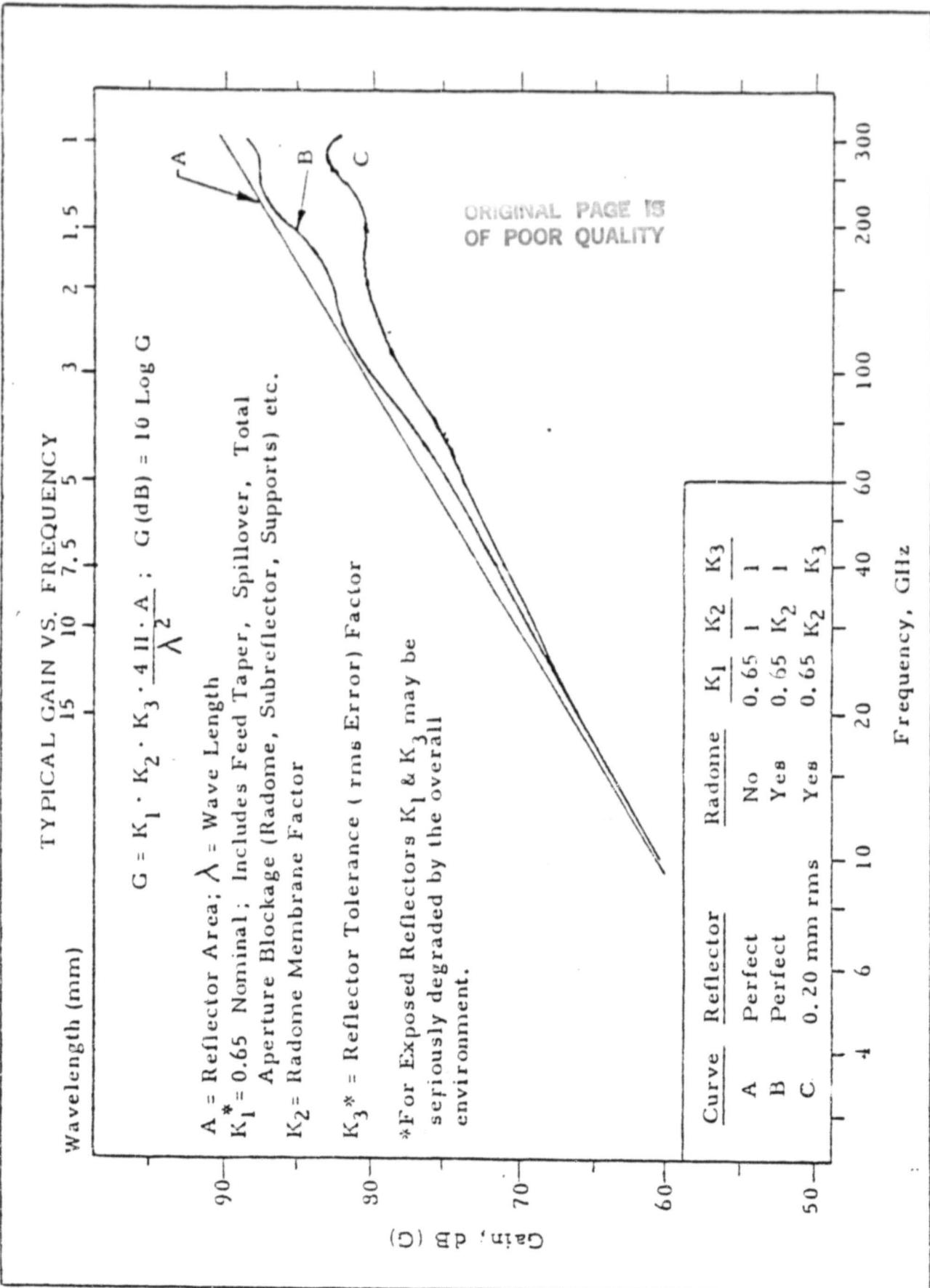
No costs were obtained, but they are undoubtedly very high. ESSCO is studying projected costs for quantity production (10 per month) in 2-3 years time, but no data is available at present. Some economies are obvious, particularly in the pointing systems, since full motion is not required for synchronous satellite application, nor is the extreme pointing accuracy.

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Loss Elements vs Frequency - ESSCO Synergised Antenna Subsystem

Figure A-4



Typical Gain vs. Frequency - ESSCO 45 ft. (13.7m) Diameter
Synergised Antenna Subsystem

Figure A-5

NASA REPORT NO. 1-4-W-1-T3

TASK 3 REPORT
PLANNING ASSISTANCE
FOR THE
30/20 GHZ PROGRAM
REVIEW OF SPECIFIED CONCEPTUAL
DESIGNS AND RECOMMENDATIONS

NASA Contract No. NAS3-22461 Task 3

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Date: July 16, 1981

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SECTION I
TASK REPORT 3
INTRODUCTION

1.0 OBJECTIVES

Under the requirements of NASA Contract No. NAS3-22461, Western Union was tasked to review, comment and offer recommendations on TRW, Hughes, Ford, GE and RCA conceptual designs for 30/20 GHz trunking and CPS communication systems. As a part of Western Union's Task 3 efforts, the multiple concepts developed by each of the contractors were reviewed relative to NASA SOW and Western Union's perception of 30/20 GHz communication system requirements based on the results of earlier Western Union market demand assessment studies and Western Union's functional design based on the market demand forecasts and system technical characteristics necessary to satisfy performance objectives.

The multiple concepts development efforts were based on a single demonstration flight system. Key constraints on the contractors were cost and the launch vehicle size restricted to SUSS-A or SUSS-D for a single demonstration flight. The outputs of this task are:

- o Review of five (5) design concepts.
- o Comparison of experiment capabilities.
- o Determination of system parameters which need further effort.

1.1 GENERAL COMMENTS

Although generally all five Contractors meet the minimum NASA Statement of Work requirements for a single demonstration flight, it is Western Union's opinion that no single concept convincingly demonstrates a high degree of scalability to an operational system. Each design concept has significant features while certain aspects are lacking. A number of details are inadequate and maximum utilization of resources is not fully demonstrated. While the minimum requirements are in general satisfied, a number of assumptions appear to be made

under ideal conditions limiting the potential of the demonstration satellite system. In general, the following items are considered to be inadequately demonstrated:

- o The parameters used in the design reports for the link calculations are not consistent. The rain margin and clear weather margins are generally not adequate. Satellite location is specified to be at 100°W longitude, an essentially ideal location that does not provide the opportunity to identify technology and performance criteria necessary to fully utilize the available orbital arc and to optimize in-orbit capacity. Antenna subsystem losses are not consistent between the contractors. For example, antenna peak gain for Ford and TRW's 41 inches and 6.7 foot receive apertures is 48.0 db and 54 db respectively. Ford has 1.1 db pointing loss and 2.0 db feed loss with net gain of 44.9 db. TRW's calculation losses include 1.6 db wave guide, 2.0 db feed, 1.8 scan, 0.4 db scan and 2.2 db pointing loss with net gain of 47.1 db. The net gain comes out to be 46 db instead of 47.1 db as shown in the design reports, doubling the aperture size results in 2.2 db extra gain rather than the 6 db expected. Considering the fact the Ford's beams are 0.7° and TRW's 0.45°, some reduction in scan loss and point loss could be explained. However, increasing the aperture size has not resulted in a significant increase in gain. A baseline loss budget needs to be established to fully grasp the link calculation in order to ascertain that system availability requirements are being met.
- o The Hughes report indicates work being done on 12.5 and 20 watt spacecraft TWTAs. It is not clear why TRW, Ford have used 30, 35, 42 and 7.5/75 watts TWTAs, respectively, in their link calculations. The design parameters used should be consistent with the technology development for the flight system.

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- o The power requirement, communication subsystem payload and launch weight estimates vary over a large range. TRW's concept II has a 416 lb communication subsystem weight and 2478 lb launch weight and 130% watt power requirement. Ford, however, with a smaller antenna and reduced throughput has 188 kg (415 lb) communication subsystem weight, 1248 kg (2750 lb) launch weight and 1147.4 watts power requirement. RCA's Concept 1A with a higher throughput and somewhat similar configuration to Ford's has dry weight of 400 lb and 500 watt power requirement. Furthermore, the criteria for weight margin is not uniform. TRW's margin is based on 15% of communication subsystem weight and 8% of bus weight whereas the other reports use maximum capability criteria for weight margin, the source of which is not clear. A baseline power and weight estimate for comparison and satisfactory accuracy should be established. We suggest that the weight estimate be categorized for (a) communication subsystem weight (b) beginning of orbit weight of the spacecraft for a specified useful life of the satellite.
- o None of the designs has taken into account degradation caused by co-channel interference, TWT non-linearities and various filtering functions to assess the end-to-end link performance.
- o Although the trunking user requirements are reasonably well defined, the status of the CPS system user requirements are not well defined, in spite of the fact that in general, minimum requirements set forth in the SOW are met. The definition of a CPS station which will be compatible with the user requirement at a competitive cost to the user is not addressed by any contractor.

- o A comparison of beam scanning vs. beam hopping antenna subsystem has not been investigated by any of the contractors.
- o Although simultaneous trunking and CPS service is not required in accordance with the SOW, it represents a real operation situation. TRW Concept I, Ford Configurations I and II, and RCA Concept 1A have this capability. However, Ford's Configuration II appears to be the most flexible.
- o Hughes concepts appear to be tailored towards video conferencing. No baseband processing is suggested.
- o GE has an interesting beam topology for frequency reuse, however, the CPS system has only limited demonstration capability.
- o Hughes link budget indicate totally inadequate clear weather margin, and therefore availability during rain is not satisfied. Adequate clear weather and rain margin should be available to overcome slowly varying environmental effects, seasonal and diurnal effects. Important aspects of rain attenuation with experimental results are described in Reference 1.
- o The 12 Meter Antenna proposed by TRW in Concept I and II for diversity-pair trunking stations does not appreciably improve the rain availability compared to a 5.0 meter antenna, but does provide additional clear weather. The details of the link calculation are not given and 3.0 db clear weather margin is claimed in the report.
- o None of the concepts directly address the traffic pattern and its impact insofar as the satellite design is concerned. An optimum time slot algorithm for a given traffic matrix

should be developed. Various approaches are discussed in Reference 2.

- o Ford and Hughes apparently do not plan to use monopulse for antenna pointing. This could result in increasing pointing loss, further deteriorating already marginal link performance.
- o Selection criterion for a suitable IF is not presented. Generally, it has been chosen approximately around 4 GHz. It should be as high as possible to eliminate images, preferably close to 8 GHz, and, of course, it should be compatible with the IF chosen for the BPU, TDMA switch and FDMA routing concepts.
- o The Baseband Processor Unit (BPU) implementation proposed by the Contractors and the BPU system concept proposed by Motorola have substantial differences. The Motorola concept is compatible with high data rate transmission and can accommodate six scanning beams and five (out of eighteen) hopping beams, each hopping over three to five fixed beams. In the proposed concepts by the five contractors, the full utilization of Motorola's BPS is lacking.
- o TRW has proposed extensive instrumentation for various measurements aboard the spacecraft. However, the effect of this instrumentation insofar as weight, power requirement and cost have not been fully discussed. Other contractors have not presented any instrumentation and various parameters they intend to monitor and measure.
- o Only Ford's beam plan has both horizontal and vertical polarization capability for the Washington, D.C. scanning beam. The scanning beam has limited range to test inter-beam interference.

SECTION II

DEMONSTRATION SYSTEM DESIGN REQUIREMENTS

2.0 INTRODUCTION

The objective of this section is to review, discuss and evaluate the various system design concepts proposed by the Contractors, consistent with the requirements set forth for space, ground and control segments for 30/20 GHz operational system for the three categories of the carriers, namely trunking, CPS and CPS/trunking. The main objectives of the contractors Task 4 are centered in development of 30/20 GHz system concepts which result in reduced cost for the demonstration model for service and technology experiments leading towards an advanced operational communication satellite in 1990-2000 time frame to satisfy the functional requirements for the space, ground and control segments for various classes of carriers. These should meet primary objectives of capacity, availability, interconnectivity based on a projected share of the forecasted communications market in the 1990-2000 period.

Under NASA Task 4, the design efforts of the Contractors were to be addressed to the entire space, ground and control segment sub-system for demonstration of 30/20 GHz network concepts such that a practical demonstration cost target could be established. The objective of the demonstration satellite is to establish the feasibility of a fully operational satellite communication network to be operated by various classes of carriers, i.e., trunk only, customer premise service only and trunk/CPS. Although the Task 4 effort is directed towards the demonstration satellite, under cost and payload constraints, the system design must be scalable to a fully operational commercial communication satellite network.

This Task Report is a comprehensive review of the design concept reports submitted to NASA under Task 4 by the following Contractors:

1. TRW, "30/20 GHz Communication System, Task 4 Report Final Concept Designs, January 28, 1981," Document No. 36565-017.
2. Hughes Task 4, "Phase II Flight Experiment System Preliminary Design Report" dated February 3, 1981.

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3. Ford Aerospace and Communication Corporation "30/20 GHz System Configuration Study" dated January 30, 1981.
4. General Electric "30/20 GHz Demonstration System SS4S-D/BSE review No. 2" dated January 1981.
5. RCA Astro "Conceptual Design of a 30/20 GHz Demonstration System" Preliminary Review, dated February 9, 1981.

The baseline design requirements are derived from "Requirements Determination for the Demonstration of 30/20 GHz Communication System" SOW modified in accordance with the results of review meetings between NASA and the Phase II contractors. The baseline system has been defined to demonstrate the technology and system performance for two basic types of communication services: Trunking and Customer Premise Services.

The present thinking is towards a single flight using an existing spacecraft bus with minimum modifications with an objective to limit the launch vehicle to SUSS-A as an upper bound.

2.1 TRUNKING REQUIREMENTS

The basic requirements for the baseline trunking system, from the SOW, are:

- Provide SS-TDMA and optionally, FDMA transmission capabilities (simultaneous operation not required)
- Support T3/T4 user interface rate in SS-TDMA and FDMA mode
- Capable of achieving high nodal availability (0.9999) using diversity earth stations and combination of fixed margin and adaptive compensation techniques
- Capability of SS-TDMA between up to seven fixed beams, although only four beams may be operated at one time.

2.2 CPS REQUIREMENTS

Basic requirements for the baseline CPS system, from the cited SOW, are:

- Provide TDMA transmission capability with nominal burst rates of 32/128 mbps on the uplink and 256 mbps on downlink
- Provide on-board baseband switching/routing capability
- Provide CONUS coverage using scanning beam antennas
- Capable of achieving a 0.999 link availability with a combination of fixed margin and adaptive compensation techniques
- Low cost user terminals
- Capable of supporting user rates ranging from 64 kbps-6.3 mbps.

2.3

GENERAL CONTEXT AND COMMENTS ON BASIC SYSTEM ISSUES

Although the concepts proposed by the five contractors are well conceived there are significant variations of concepts among the contractors insofar as system configuration, throughput capacity and depth of details. There are also significant departures from the statement of work. The space segment configuration and its capabilities proposed by the Contractors are chosen to be compatible with the launch vehicle required to deliver the payload into orbit. The significant issues to be addressed in the demonstration flight are:

- Antenna subsystem and beam characteristics
- Network synchronization and timing
- Baseband processor
- Availability analysis
- Master control station
- Technology experiments
- Earth station interface

In view of the fact that the present effort is towards an evolutionary flight system with cost and launch vehicle constraints, it is essential that the concepts proposed by Contractors be demonstrated to a high confidence level which verifies a smooth transition from demonstration system to a fully operational system. Based on Western Union's perception of operational system requirements, the following demonstration system considerations are not addressed adequately and require further investigation:

- Frequency reuse
- Antenna subsystem and beam topology
- Link availability
- Synchronization and timing
- Terrestrial interface
- Adequately defined user requirement of CPS
- Consideration of existing and projected traffic requirements and its impact on space segment design.

SECTION III

REVIEW OF TRW, HUGHES, FORD, GE, RCA DESIGN CONCEPTS

A brief review of the five contractors design report is summarized in this section. A tabulated presentation of the five design reports is given in Figure 1.

3.1 TRW

TRW has proposed three (3) space segment design concepts.

3.1.1 Concept I

This concept utilizes a single 13.5 foot antenna for combined fixed and scanning beam operation. Two identical apertures are employed; one each for the Eastern and Western regions of CONUS. Transmit and receive feeds are diplexed to separate the 30 and 20 GHz RF signals. The fixed and scanning beams are orthogonally polarized. The antenna gains are 51.8 db and 51.6 db for transmit and receive, respectively, with miscellaneous losses included.

This concept employs seven transmit and receive fixed beams, of which only four are simultaneously active. The fixed beams are pointed towards Cleveland, Los Angeles, New York/Boston/Tampa and Seattle/Washington, D.C. The fixed and scanning beam transmitters are 10/2.5 and 42 watt TWTAs, respectively. The trunking transmission data rate is 512 mbps per beam. Connectivity between beams is provided by the SS-TDMA switch. In CPS operation there are four channels operating at 32 mbps and one at 128 mbps. The total throughput for trunking and CPS are 2.048 gbps and 768 mbps, respectively. Connectivity for CPS operation is provided by the baseband processor. Simultaneous trunk and CPS operation is permitted. The ground station sizes for trunk and CPS is 12 and 3.5 meters, respectively.

3.1.2 Concept II

This concept is a reduced cost version of Concept I. The spacecraft antenna has reduced gain and pointing loss. CONUS coverage is provided by two

TRW			HUGHES			
LAUNCH VEHICLE	SUSS-A	SUSS-B	SUSS-A	SUSS-B	SUSS-A	CONFIGURATION I
PAYOUT WEIGHT	791 LBS.	416 LBS.	399 LBS.	365 LBS.	810 LBS.	309 LBS.
SPACECRAFT DRY WEIGHT	1971 LBS.	1700 LBS.	1700 LBS.	NOT SPECIFIED	NOT SPECIFIED	1903 LBS.
SPACECRAFT POWER	1107 WATTS	1308 WATTS	1300 WATTS	990 WATTS	938 WATTS	961 WATTS
SPACECRAFT DESIGN LIFE	8 YEARS	7 YEARS	7 YEARS	7 YEARS	7 YEARS	8 YEARS
SPACECRAFT ANTENNA SIZE TX/RX	13.8/13.8 FT.	10/6.7 FT.	10/6.7 FT.	1.8/1.8 METERS	8.8/8.8 METERS	6.8/4.1 INCHES
SPACECRAFT ANTENNA GAIN	81.8 dB (INCLUDES LOSSES)	47.1 dB (INCLUDES LOSSES)	SAME AS CONCEPT II	40.7 dB/50.7 dB (NO LOSSES INCLUDED)	61.6/55.6 dB (NO LOSSES INCLUDED)	40 dB (NO LOSSES INCLUDED)
BEAM WIDTH	0.3°	0.45°	0.45°	0.8°	0.8°	0.7°
NO. OF FIXED BEAMS & LOCATION	7 FIXED, ANY 4 ACTIVE AT ONE TIME CLE, LA, NY OR BOSTON OR TAMPA SEATTLE OR D.C.	SAME AS CONCEPT I	SAME AS CONCEPT I	6 FIXED BEAMS (NO LOCATION SPECIFIED)	6 FIXED BEAMS (NO LOCATION SPECIFIED)	7 FIXED, ANY 4 ACTIVE AT ONE TIME BOSTON OR NEW YORK, D.C., OR, HOUSTON, LA OR SEATTLE
NO. OF SCANNING BEAMS	8 INDEPENDENT TX/RX BEAMS ONE BEAM FOR EACH SECTOR FULL CONUS COVERAGE	8 INDEPENDENT TX/RX BEAMS ONE BEAM FOR EACH SECTOR. ABOUT 20% CONUS COVERAGE	SAME AS CONCEPT II	1 BEAM FOR TX/RX	8 BEAMS FOR TX/RX	8 INDEPENDENT TX/RX BEAMS ONE BEAM FOR EACH SECTOR, 80% POSITIONS ABOUT 20% CONUS COVERAGE
TRUNK DATA RATE	810 NOPS FOR EACH BEAM	SAME AS CONCEPT I	SAME AS CONCEPT I	180 NOPS PER BEAM	120 NOPS PER BEAM	100 NOPS
THROUGHPUT	2040 NOPS	SAME AS CONCEPT I	SAME AS CONCEPT I	810 NOPS (SAME FOR CPS FOMA)	1024 NOPS (SAME FOR CPS FOMA)	810 NOPS
CPS DATA RATE	4 AT 32 NOPS, 1 AT 120 NOPS	4 AT 16 NOPS, 1 AT 64 NOPS	164 AT 64 KOPS, 16 AT 772 KOPS AT 1,844 KOPS + SCPC	2 AT 32 NOPS (FOMA), 10 AT 6.3 NOPS (FOMA)	2 AT 32 NOPS (TOMA), 20 AT 6.3 NOPS (FOMA)	32 NOPS
INPUT	768 NOPS	180 NOPS	83.0 NOPS	60 NOPS	180 NOPS	
SATELLITE HPA SIZE + TRUNK	10/8.5 WATTS (TOMA/SSPA)	89.8/7.4 WATTS	89.8 WATTS	10.8 WATTS	10.8 WATTS	8 WATTS - SSPA
SATELLITE HPA SIZE + CPS	68 WATTS	38 WATTS	30 WATTS	20 WATTS (TOMA) 10.8 WATTS (FOMA)		7.8/7.8 WATTS - TOTIA
TRUNK E.S. SIZE 8 HPA SIZE	18 METERS 100 WATTS	SAME AS CONCEPT I	SAME AS CONCEPT I	8 METERS 800 WATTS	8 METERS 100 WATTS	8 METERS 80/800 WATTS
CPS E.S. SIZE 8 HPA	3.5 METERS 10 WATTS	3.5 METERS 10 WATTS	16 FOR 64 NOPS, 2H FOR 772 NOPS 8.00 FOR 1,844 NOPS	8.0 METERS, 100 WATTS (TOMA) 8.0 METERS, 20 WATTS (FOMA)	8.0 METERS, 10.8 WATTS (TOMA) 8.0 METERS, 10 WATTS (FOMA)	3.5 METERS OR 8 METERS 16/800 WATTS
RAIN MARGIN FOR TRUNK UP/DOWN	20/10 dB	18.8/10 dB	SAME AS CONCEPT II	NOT SPECIFIED	NOT SPECIFIED	8.8/8.3 dB
TRUNK ADAPTIVE STATE VARIABLES UP/DOWN	NONE/SAT, PWR	NONE/SAT, PWR	SAME AS CONCEPT II	NOT SPECIFIED	NOT SPECIFIED	7/8 CODE, E.S. POWER
TRUNK AVAILABILITY	0.9999	0.9999	0.9999	0.9999 (NOT ACHIEVED)	0.9999 (NOT ACHIEVED)	0.9999
DATA MARGIN FOR CPS UP/DOWN	10.4/10.3	14.7/10.3 dB	18.6 dB	NOT SPECIFIED	NOT SPECIFIED	8.8/8.3 dB
ADAPTIVE STATE VARIABLES UP/DOWN	NONE/EC	NONE/EC	NONE/NONE	NOT SPECIFIED	NOT SPECIFIED	7/8 CODE, E.S. POWER
CPS AVAILABILITY	0.999	0.999	0.999	0.999 (NOT ACHIEVED)	0.999 (NOT ACHIEVED)	0.999
SIMULTANEOUS TRUNK & CPS	YES	NO	NO	NO	NO	YES
BASIC PATH PROCESSOR	YES	YES	NO (SS-TOMA CROSS CONNECT SWITCH)	NO	NO	NO

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FOLDOUT FRAME

FORD		62		62A	
CONFIGURATION I	CONFIGURATION II	ALTERNATIVE A	ALTERNATIVE B	CONCEPT I	CONCEPT II
TRUNK SS-TDMA	CPS SS-TDMA	TRUNK SS-TDMA	TRUNK SS-TDMA	TRUNK SS-TDMA	TRUNK SS-TDMA
		SS-TDMA	SS-TDMA	SS-TDMA	SS-TDMA
BUSY-D	BUSY-D	BUSY-D	BUSY-D	BUSY-D	BUSY-D
402 LBS.	396 LBS.	NOT AVAILABLE	NOT AVAILABLE	400 LBS.	407 LBS.
1802 LBS.	1802 LBS.	NOT AVAILABLE	1720 LBS.	NOT SPECIFIED	NOT SPECIFIED
981 WATTS	1147 WATTS	NOT AVAILABLE	941.3 WATTS	800 WATTS	800 WATTS
8 YEARS	8 YEARS	NOT AVAILABLE	7 YEARS	8 YEARS	8 YEARS
67/41 INCHES ¹	67/41 INCHES	37/35 INCHES	37/35 INCHES	NOT SPECIFIED	NOT SPECIFIED
40.00 (NO LOSSES INCLUDED)	40.00 (NO LOSSES INCLUDED)	44.3.00	44.3.00	NOT SPECIFIED	NOT SPECIFIED
0.7°	0.7°	1.8°	1.8°	NOT SPECIFIED	NOT SPECIFIED
7 FIXED, ANY 4 ACTIVE AT ONE TIME CLE EUSTON OR MIAMI / WASH D.C., OR, HOUSTON, LA OR SEALITE	SAME AS CONFIGURATION I	13 BEAMS COVERS CONUS 4 ACTIVE BEAMS FOR TRUNK	SAME AS ALTERNATIVE A	4 FIXED BEAMS NY, CLE, WASH, D.C., LA	SAME AS CONCEPT I
8 INDEPENDENT TX/RX BEAMS ONE BEAM FOR EACH SECTION, 6 BEAM POSITIONS APPROX. 200 CONUS COVERAGE	SAME AS CONFIGURATION I	NO SCANNING BEAMS BEAM HOPPED SWITCH PROVIDE CONNECTIVITY, 10-ZON CONUS COVERAGE	SAME AS ALTERNATIVE A	8 SCANNING BEAMS, EACH BEAM COVERS ONE SECTOR	SAME AS CONCEPT I
100 NOPS 818 NOPS	SAME AS CONFIGURATION I	100 NOPS 818 NOPS (TDMA), 286 NOPS (FDMA)	SAME AS ALTERNATIVE A	266 NOPS PER BEAM 1004 NOPS	SAME AS CONCEPT I
30 NOPS	30 NOPS	6+10 NOPS (TDMA) 36 OR 72 NOPS (FDMA) 1 NOPS PACKET, 203 NOPS TOTAL	SAME AS ALTERNATIVE A	32 NOPS NOT SPECIFIED	SAME AS CONCEPT I
8 WATTS - SSPA	7.8/7.8 WATT - TWT	80 WATTS	80 WATTS	NOT SPECIFIED	NOT SPECIFIED
7.8/7.8 WATTS - TWT	SAME AS CONFIGURATION I	8 METERS 200 WATTS	8 METERS 200 WATTS	NOT SPECIFIED	NOT SPECIFIED
8 METERS 20/200 WATTS	SAME AS CONFIGURATION I	8 WATTS	SAME AS ALTERNATIVE A	8 METERS	8 METERS
3.5 METERS OR 8 METERS 10/800 WATTS	SAME AS CONFIGURATION I	3 METERS 10 WATTS	SAME AS ALTERNATIVE A	8 METER OR 3 METERS	8 METER OR 3 METERS
3.0/3.0.00	SAME AS CONFIGURATION I	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED
T/O CODE, E.S. POWER	SAME AS CONFIGURATION I	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED
0.999	0.999	0.999	0.999	0.999 (NOT SHOWN)	0.999
0.999	SAME AS CONFIGURATION I	NOT SPECIFIED	NOT SPECIFIED	184.00	184.00
T/O CODE, E.S. POWER	SAME AS CONFIGURATION I	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED	NOT SPECIFIED
0.999	0.999	0.999	0.999	0.999	0.999
YES	YES	NO	NO	NO	NO
NO	YES	NO	NO	NO	YES

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FIGURE 1

apertures. The receive antenna is a 6.7 foot reflector and the transmit antenna a 10 foot reflector. The beam width in both cases is 0.45° . The net transmit and receive antenna gains are 47.1 db and 47.2 db, respectively. The Concept II payload is designed primarily for operation in one of the following two modes:

1. Four active trunking terminal beams
2. Two fixed beams plus two scanning beams.

The cross-connect between the TDMA switch and the baseband processor is to provide CPS users in the fixed beam area the capability to access the CPS system. Los Angeles has been allocated a full-time SS-TDMA channel to insure fulltime autotrack capability. The satellite EIRP for fixed beams in Concept II is essentially the same as in Concept I. The Satellite power is increased to offset the loss in Satellite gain due to the smaller ten foot aperture. Power control to achieve the 7.4/29.5 watt for clear weather and rain operation. The trunk mode signalling rate is 512 mbps. In the CPS mode the data rate is four channels at 16 mbps and 64 mbps, respectively. This concept demonstrates CPS operation with terminal located in both the fixed and scanning beam deployment areas. Complete connectivity is provided by the IF switch in the trunk mode and the baseband processor in the CPS mode. The ground stations for trunk and CPS are 12 and 3.5 meters, respectively.

3.1.3 Concept III

This concept, like Concept II, employs separate 10.7 foot and 6.7 foot antenna apertures for transmit and receive, respectively and functionally is the same as Concept II. No scanning beams are generated. Instead, a hyperbolic subreflector is used to generate additional fixed beams to provide approximately 20% CONUS coverage with appropriately polarized feed clusters. The polarization of the fixed beams may vary with location. This concept is different from Concept II, where fixed beams are on a single polarization and scanning beams are on orthogonal polarization.

This concept has two modes of operation; four active trunking beams or four active CPS beams. The baseband processor is replaced by an SS-FDMA filter processor for CPS operation. Deletion of the variable Power Divider scanning

beams and the baseband processor results in reduced payload weight. The data rate in the trunking mode is 512 mbps per beam. For the CPS mode the SS-FDMA operation provides 144 channels at 64 kbps, 16 channels at 772 kbps, and 8 channels at 1.54 mbps for SCPC transmission. The throughput per beam in the CPS mode is 33.86 mbps. The trunking subsystem uses a 7.4/29.5 watt TWTA transmitter and the CPS subsystem uses a 30 watt TWTA transmitter.

3.2 HUGHES

Hughes has proposed two concepts.

3.2.1 Concept 3

Concept 3 uses a 1.8 meter aperture with on-axis antenna gains of 48.1 db and 52.7 db for transmit and receive. With 0.9 db scan loss and a 2 db contour level, the net gain is 45.2 db and 48.5 db for transmit and receive. Any four (4) beams are active at any one time and complete connectivity is achieved with a 4 x 4 SS-TDMA switch. The burst rate is 128 mbps per beam with a total throughput of 512 mbps. The Customer Premise Service is provided with one scanning beam with 16 positions. The data rate for the CPS is 32 mbps for each of two channels with a total throughput of 64 mbps. This concept also has an optional feature for FDMA transmission using four fixed beams. Data rate for this transmission mode is 128 mbps with a total throughput of 512 mbps. This concept allows only one mode, i.e., TDMA or FDMA, at a time. There is no cross-connect between the CPS and trunking. For the trunk mode the downlink transmitter is 12.5 watts and in the CPS mode it is 26.0 watt, both TWTA's. The ground stations are equipped with five meter and 3.5 meter for trunking and CPS, respectively.

3.2.2 Concept 4

This concept utilizes a 2.6 meter aperture with on axis gains of 51.0 db and 55.6 db for transmit and receive, respectively. Including scan loss of 0.6 db and 1.4 db and 2 db contours, the net gains for transmit and receive are 48.4 db and 52.2 db, respectively. There are eight (8) fixed beams for trunking and complete connectivity is provided by a 8 x 8 SS-TDMA switch. The burst rate is 128 mbps with a throughput of 1024 mbps. Customer premise service is provided by two (2)

scanning beams with two carriers in each beam. The burst rate is 32 mbps with a total throughput of 128 mbps. This concept also has FDMA transmission using eight fixed beams. The data rate for the FDMA transmission mode is 128 mbps. The TDMA and FDMA mode can be operated on a non-simultaneous basis only. No cross-connect capability exists between the trunking and the CPS systems. The downlink transmitter uses a 12.5 watt TWTA. The ground stations are with five meters for trunking and five meter/three meter for CPS. Earth station transmitter power for trunk and CPS is 100 watt and 12.5 watt, respectively. In the FDMA mode the CPS configuration provides twenty (20) carriers each with 6.3 mbps.

No Baseband Processor Unit (BPU) is proposed for either Concept 3 or 4. Up/Down-link margins of 10/5 db are provided without the use of FEC; in general five meter CPS stations are required.

3.3 FORD AEROSPACE

Ford Aerospace has proposed the following two (2) concepts.

3.3.1 Configuration I

This configuration utilizes single reflector antennas of 68 inch and 41 inch diameter for transmit and receive. The peak gain and beam width is 48 db and 0.7° beam width, respectively. The aperture generates seven (7) fixed beams for trunking pointed at (i) Cleveland (ii) Boston or Miami (iii) Washington, D.C. or Houston (iv) Los Angeles or Seattle. Only four (4) of the seven (7) beams are active at any one time. The burst rate is 128 mbps per beam with a total throughput of 512 mbps for trunking. The downlink uses an eight watt solid state power amplifier.

For CPS service two active beams for two coverage areas of six (6) beam positions is proposed. The transmit and receive beam for each zone is independently controlled. Satellite antenna gain and beam width is 48 db and 0.7° beam width respectively, the same as for the fixed beams. The burst rate is 32 mbps for each beam, resulting in a CPS throughput of 64 mbps. The transmitter for the downlink transmission uses dual mode 7.5W/75W TWTA. The ground station for trunking is five meters and 20/500 watt transmitters are used for clear weather

and rain. The ground station size for CPS is five meters and three meters and the transmitter power is 10/300 watts for clear weather/rain conditions. Simultaneous trunking and CPS operation is allowed in this configuration.

3.3.2 Configuration 2

The antenna and beam characteristics in this are the same as in Configuration 1. This configuration also includes two 60 mbps FDMA channels, baseband processor and beacon package for EHF experiments.

Simultaneous trunking and CPS operation is allowed in this operation.

3.4 GENERAL ELECTRIC COMPANY

General Electric has proposed two configurations. The antenna and feed configuration is the same for both configurations. The transmit and receive apertures are 37 inch and 25 inch respectively. The antenna generates 13 beams with 1.3° beamwidths to provide complete CONUS coverage. The antenna has a peak gain of 44.3 db, average gain of 43.0 db and minimum gain of 36.7 db at beam cross overs.

3.4.1 Alternative A

This alternative proposes SS-TDMA, SS-FDMA and a packet switch processor. The payload uses a 13×13 TDMA switch to provide complete connectivity between the 13 beams in the TDMA mode. A 13:1 beam hopper switch connects the beams to a processor. On the downlink a 1:13 switch connects the output of the processor to its destination. The packet and TDMA are multiplexed for each beam and amplified by a 10 watt amplifier. In the TDMA trunking mode the SS-TDMA switch is used as a 4×4 switch. Each beam has a data rate of 128 mbps with a total throughput of 512 mbps. In the FDMA mode a single channel carries 128 mbps and the FDMA trunking mode throughput is 256 mbps.

In the SS-TDMA CPS mode, the data rate is 6-10 mbps for each beam. The total throughput for the 13 beams is 78-130 mbps. In the SS-FDMA CPS mode, the thirteen beams are reduced to six beams by beam combining. Each of the six

beams is 10 MHz bandwidth. In addition two 36 MHz paths can be shared by the six channels.

The packet switch throughput is 1 mbps and connectivity is provided by the packet processor via a beam hopper switch. No baseband processor is used in the CPS mode. Simultaneous CPS and trunking is also not allowed and there is no cross-connect between CPS and trunk.

3.4.2 Alternative B

This configuration is essentially the same as Alternative A. The beam combining is done at IF and the SS-FDMA switch is reduced from a 13×13 to 6×6 . This configuration makes more efficient use of the transponder as compared to Alternative A and results in reduced weight.

3.5 RCA

RCA Astro has proposed two concepts.

3.5.1 Concept I

This concept proposes four fixed beams for trunking and two scanning beams for two sectors with either beam switching or transponder switching. The trunking transmission rate is 256 mbps with a total of 1024 mbps and the CPS transmission rate is 32 mbps. This concept does not have cross-connect between CPS and trunking. Switching for CPS is done at IF. Ground interface is with five meter antennas for trunk and five meter/three meter for CPS.

3.5.2 Concept 1A

This concept is essentially the same except additional capabilities in descending order are included. The additional capabilities are: baseband processor, SS-FDMA, data rate variation, simultaneous operation of trunk/CPS, and eclipse operation.

SPACECRAFT DESIGN CATEGORIES

Based on the orbit transfer weight at separation from shuttle and the launch vehicle required to transfer the payload into synchronous orbit the design concepts can be classified in the following two categories:

1. SUSS-D

Hughes Concept 3

Ford

GE

RCA

2. SUSS-A

TRW

Hughes Concept 4

Based on weight estimates of various designs, with the exception of GE, the larger payload of each contractor has enhanced capability. In the case of GE, by beam hopping and combining at IF results in lighter payload with the same performance. The design concepts based on descending payload are as follows:

SUSS-D

RCA Concept 1A - 437 lb

Ford Concept II - 300 lb

GE Alternative 1B - 288.6 lb

Hughes Concept 3 - 265 lb

SUSS-A

TRW Concept 1 - 791 lb

Hughes Concept 4 - 518 lb

Since the launch vehicle size to deliver the total weight of the spacecraft and support system from the shuttle bay to synchronous orbit is of interest, it will be more meaningful to consider the aggregate weight of communication payload, spacecraft bus and fuel requirement for station keeping as a function of spacecraft life. If sufficient weight margin is available the secondary

experiment's weight may be included. Specifying the maximum communication payload without regard to spacecraft bus weight may be ambiguous and could result in excessive weight margins for the comprehensive flight system.

It is Western Union's opinion that the following guidelines may be useful for the demonstration flight:

- o A two year useful life of the satellite
- o Use the design concept with the largest payload
- o Limit the scope to only primary experiments and delete the secondary experiments altogether. As many as possible primary experiments should be conducted to achieve a high degree of confidence in transition from a demonstration system to an operational system.

SECTION IV

EXPERIMENT PLANS

4.1 CAPABILITIES

4.1.1 TRW

TRW has developed three design concepts. Each design concept can provide transmission system capabilities to conduct most of the important service, technology and combined service/technology experiments identified in Sections 4.2, 4.3 and 4.4.

Propagation experiments mentioned in Sections 4.2, 4.3 and 4.4 cannot be accommodated in all design concepts since there is no CONUS coverage beacon incorporated in the flight system. Furthermore, some experiments such as scanning spot beam, baseband processor, etc., cannot be accommodated in Concept III, since a fixed beam SS-FDMA CPS network with no spacecraft processing has been utilized.

4.1.2 Hughes

Hughes has developed two design concepts (Concept 3 and Concept 4). Each design concept can provide transmission system capabilities to conduct most of the important experiments identified in Sections 4.2, 4.3 and 4.4. The baseband processor evaluation experiment cannot be supported since Hughes does not utilize a baseband processor in either of the design concepts.

4.1.3 General Electric

General Electric proposes two alternative systems. Alternative A and Alternative B are essentially similar in their impacts on the experiments objectives. A beacon is incorporated in Alternative B so that most of the important propagation experiments can be accommodated. There is no beacon incorporated in Alternative A. No scanning beam antenna is utilized in either alternative, consequently, it is not possible to conduct the experiments which require a scanning beam antenna. Also, due to the use of a modified processor, baseband

processor experiments cannot be conducted by the same approach as mentioned in the Experiments Planning Document.

It is apparent that several experiments have been modified in their approach to satisfy GE design concepts, however, there is no elaboration on the approach or the measurement techniques.

4.1 4 RCA Astro

RCA has proposed two concepts (Concept I and Concept IA). Although these two concepts are capable of supporting most of the important experiments, it is not clear, however, that an experiment instrumentation concept is developed or the associated telemetry or order wire link sized to collect and process the data.

4.1.5 Ford Aerospace

Ford Aerospace has proposed two concepts. The main difference in the impact on the experiment plans is that in Configuration 2, a baseband processor and a beacon package for EHF experiments have been incorporated. Both configurations, however, can accommodate most of the important experiments.

4.2 TECHNOLOGY EXPERIMENTS

The following set of experiments are necessary to demonstrate the critical technology of the 30/20 GHz communications subsystems.

4.2.1 PT-1 (Transponder Performance Evaluation)

The objective of this experiment is to determine transponder performance as a function of time in space environment and obtain fundamental data for further advancement of transponder components.

The satellite transponder and associated antennas form the primary portion of the communications subsystem on a communication satellite. Critical parameters to be measured include gain, phase noise introduced by frequency

translation, delay, filter distortion effects caused by channelization filters, and interference for all transponder path configurations.

4.2.2 PT-2 (20 GHz TWT Transmitter Experiments)

The objective of the experiment is to demonstrate an efficient, multi-level 20 GHz TWT transmitter and evaluate its performance on-orbit. In the analysis of baseband distortion, it is important to understand the nonlinearity characteristics of the TWTA which is the primary contributor to transponder non-linearity. These characteristics may be affected by switching from one mode to another or TWT input backoff in steps of 1 db by ground command.

4.2.3 PT-3 (Multiple Spot and Scanning Beam Antenna Evaluation) and PT-15 (30/20 GHz Multiple Scanning Spot Beam Antenna)

These two experiments should be conducted as one experiment. The objective is to determine and evaluate beam pattern, gain stability and coupling and to develop antenna technology so that high gain and high capacity scanning beams can be fabricated.

This experiment is critical for the assessment of antenna design. Concern with scanning beam systems include capacity information, scanning losses, synchronization complexity, gain contour, and slope effects. Concerns with spot beams antennas include switching hardware complexity, to confirm the choice of the frequency/polarization plans, the isolation between fixed and scanning spots (when the scanning are steered through or near the fixed beams antennas) should be measured. Specific parameters to be measured include antenna gain, antenna pattern, polarization isolation, beam pointing, etc.

4.2.4 PT-4A (Impatt Solid State Transmitter) PT-4B (GaAsFET Solid State Transmitter)

The objective is to determine communications performance, life and stability under space environment. Obtain fundamental data to guide future use of Impatt and GaAsFET microwave power devices.

Solid state microwave power devices used in suitable power combining circuits are promising candidates for future efficient, reliable spaceborne transmitter applications.

4.2.5 PT-7 (IF Switch Matrix Performance Test)

The objective of this experiment is to evaluate the performance of the IF switch matrix in the operational environment.

The IF switch is one of the new technologies being developed by NASA. The critical design parameters, which must be tested with the switch at maximum reconfiguration rate, include connectivity, random switching, switching speed, beam isolation, etc. Reliability of the IF switch is a major concern. A self-test feature checking any in/out connection by ground command would be useful.

4.2.6 PT-9 (Base Band Processor (BBP) Evaluation)

The objective of this experiment is to establish the on-orbit characteristics of the BBP subsystem such as connectivity capabilities, FEC performance and its susceptibility of electrical, mechanical and radiational damage.

The Base Band Processor has been designed using several advanced technology developments. This necessitates the assessment of its characteristic, and its numerous functions on-orbit. The advanced technology developments include modulation technique, high speed baseband routing switch, modular distributed processing techniques, memory configuration and the special LSI design. Extensive tests should be conducted on the BBP functions within the satellite system architecture such as store-and-forward capacity and routing capability, isolation, redundancy capability (if used), FEC decoding (both hard and soft decision) and encoding, including bit rate reduction (if used), under varied conditions of SNR, BER, satellite positional stability, antenna pointing stability/accuracy and sync word lengths. A provision to bypass the BBP (or parts thereof) should be incorporated should an on-orbit failure require troubleshooting.

4.2.7 PT-16 (Synchronization)

The objective of this experiment is to demonstrate the feasibility of synchronizing satellite beam steering with earth station burst timing. This experiment is essential to evaluate the synchronization technique selected for the ground station network. Key areas of concern include the synchronization of burst assignments with the scanning beams, hardware and software function complexities, stability of synchronization subsystem, etc. If applicable both open-loop and closed-loop techniques should be evaluated.

4.2.8 PT-20 (Antenna Pointing Accuracy)

The objective of this experiment is to demonstrate the antenna pointing accuracy requirements of the spacecraft and the earth terminal. Monopulse feeds pointing towards one or more earth stations is required. It is important for maintaining synchronization and the communications link's performance that the antenna pointing accuracy should be compatible with the beam width. The effects of spacecraft pointing error on ground antenna tracking or pointing during normal operations and station-keeping maneuvers should be evaluated.

4.2.9 PT-21 (Interference Assessment)

The objective of this experiment is to determine the level of interference versus beam separation assuming frequency reuse. The levels of cochannel interference and cross-polarization isolation will directly affect the link's performance. The measurement of these two parameters when the number of beams is increased to about 20 beams will give an adequate assessment of the antenna sidelobe level and beam separation assuming frequency reuse. This experiment should be conducted during uniform and non-uniform loading of the beam.

4.3 OPERATING EXPERIMENTS

The following experiments are necessary to demonstrate commercial service applicability.

4.3.1 PS1 (30/20 GHz Propagation Measurements)
PS-29 (Propagation Experiment)

The objective is to measure the radio wave propagation effects and evaluate system performance on operating earth-space paths.

At 30/20 GHz, the troposphere has a significant effect on the carrier-to-noise ratio of a propagation wave. The reduction in carrier to noise ratio reduces the allowable data rate for a given bit error rate and the quality of transmission.

In the most severe cases, transmission outages will occur. Propagation measurements and studies are necessary to allow the prediction of outages with a high degree of certainty so that the means to reduce the frequency and durations of these outages can be developed. A 20 GHz beacon instead of 30 GHz beacon should be utilized for this experiment to avoid interference problems.

4.3.2 PS-10 (Bit Stability During Switching)

The objective of this experiment is to measure directly the effect of diversity switching relative to bit integrity.

Power efficient digital receivers generally require the existence of a digital clock synchronized to the received bit stream to control the integrate-and-dump or matched filter's sampling instants, or to control otherwise the timing of the output bit streams.

The received bit-transition time clock has some time jitter and frequency drift corresponding to the oscillator phase noise and path change velocity. The effect of diversity switching on bit integrity can be so severe that it causes multiplexers or switches in the data link to produce a totally corrupted bit pattern. These effects should be fully investigated.

4.3.3 PS14 (System Synchronization Evaluation)

PS-24 (Synchronization Parameterization)

These two experiments should be conducted as one experiment. The objective is to evaluate the stability of the network synchronization as a function of time and SNR and to measure the time required for resynchronization after drop-out.

Synchronization tracking loop depends on several parameters, including the phase noise in the carrier induced by various oscillator short term stability, carrier tracking-loop dynamic, transient response and acquisition, performance requirements, and signal to noise ratio in the tracking loop.

Each synchronization tracking loop requires the use of some form of phased locked oscillator tracking loop. In addition to tracking the oscillator phase noise, the loop must also acquire the carrier in a reasonable acquisition time and operate over the required range of oscillator-frequency drifts. The implications of these effects on the performance of PSK or APSK modems should be considered since the detection is only partially coherent because of the imperfect carrier tracking caused by various loop noise effects.

Results of this experiment will determine the future synchronization schemes to be considered such as length of unique words, error threshold, and modulation techniques.

4.3.4 PS-25 (Diversity Operation)

The objective of this experiment is to determine the increased availability afforded through the use of diversity techniques within a limited region of coverage and to determine the optimum spacing required for best diversity improvement.

The significant path loss variations at 30/20 GHz due to rainfall necessitates the deployment of diversity arrangements. Space diversity is one arrangement that needs to be thoroughly evaluated in terms of switching and control techniques of traffic from one site to another without interruptions and the

effects on synchronization, the relationship between separation distance, fade depth and diversity gain. This experiment is essential, since empirical data is not available to substantiate the belief that there is nearly a db for db diversity gain improvement for cases where single site attenuation exceeds the 15-18 db range.

4.3.5 PS-27 (Propagation Availability)

The objective of this experiment is to determine the service availability and individual and joint fade statistics.

The severity of rain attenuation in the 30/20 GHz band, particularly where high system availability is required, mandates that the system designer consider multiple techniques for improving system availability. These would include adaptive power control, adaptive FEC, space diversity earth station complexes, and location of the satellite within the domestic orbital arc. Experimental explorations of these and other techniques such as adaptive reduction of the transmission data rate and the reduction of the number of quantization bits for digital voice channel, are necessary for system design trade-off considerations.

4.3.6 PS-30 (User Acceptance)

The objective is to evaluate user acceptance of low cost communication versus moderate service availability.

Duration and time of occurrence of outage are important factors in determining the acceptability of low cost service. Requirements for minimum EIRP, minimum antenna size and narrowband communications (voice, facsimile, etc.) should be determined.

4.4 COMBINED OPERATION/TECHNOLOGY

The following experiments are necessary to demonstrate commercial service applicability and special technical capabilities that enhance system performance/availability.

4.4.1 PSAT-4 (Cophasing Parameterization)
PSAT-5 (Cophasing Stability Measurements)

The objective of the experiment is to determine the performance of cophasing as a function of the measurement time, the measurement format, and the signal-to-noise ratio of the system and to determine the stability of the phased array as a function of time.

The cophasing operation is the process of taking a set of array phase measurements and computing the deviations of the uplink and downlink beam from the intended direction and correcting for these deviations by updating the steering vectors associated with the phased array.

The required SNR's of the cophasing schemes are not known, nor are the measurement times and measurement format (e.g., one single measurement, or summed sequential measurement). These factors are inter-related. To obtain the data necessary for accurate design, a study of these relationships and array instabilities is required.

4.4.2 PSAT-6 (Low Bit Rate FDMA/TDMA)

The objective of this experiment is to evaluate network performance for low bit-rate (6.3 mbps) FDMA/TDMA via the emergency service channels, link performance, adaptive FEC, service quality for voice, FAX, TTY and freeze-frame TV.

Low bit-rate FDMA/TDMA service could become a very important application of 30/20 GHz communications to low cost CPS type services. Spacecraft equipment complexity, network performance and link performance need to be evaluated and demonstrated.

4.4.3 PSAT-7 (Variable Bit-Rate SS-TDMA)

The objective of this experiment is to test network synchronization for wideband communication with adaptive bit-rate.

Improved availability can be obtained by adaptive reduction of the transmission data rate, providing an increased level of energy per bit for given available transmitter power conditions. This approach should be evaluated as part of system design trade-off consideration.

4.4.4 PSAT-8 (Trunking and CPS Experiments)

The objective is to develop quantitative end-to-end system performance data for trunking and CPS under various propagation conditions with and without the aid of adaptive compensation and to develop network operational control procedures.

It is necessary to evaluate the system performance in terms of system parameters such as TDMA acquisition/reacquisition time, carrier and bit timing, BER versus E/N_0 performance, BER improvement with adaptive fade compensation, effects on system BER and synchronization due to station keeping, dynamic burst assignments, satellite switch reconfiguration, loss of primary reference bursts, and BER as function of load variations, intermodulation characteristics, BER as a function of TWT back-off and number of carriers and demonstrate the performance of a DAMA control system.

4.4.5 PSAT-11 (Adaptive Polarization)

The objective of this experiment is to develop statistical data on measured depolarization effects at 30/20 GHz as a function of rainfall statistics and to develop an adaptive polarization tracking subsystem and to evaluate its performance, particularly in heavy rain zones.

Rain depolarization is an important system and earth station design consideration, particularly in linearly polarized frequency reuse systems. Parameters to be measured include polarization shift relative to measured rain rates, BER with and without adaptive tracking, cross-polarization isolation and interference with and without adaptive tracking.

SUMMARY OF RECOMMENDATIONS

4.5.1

TRW

The following experiments will not be conducted:

- o PS-4 (Above 40 GHz Propagation)

This experiment is of lower priority since the above 40 GHz bandwidth is not expected to be used beyond the year 2000. The placement of beacons on the satellite will jeopardize the performance of other important experiments.

- o PS-27 (Propagation Availability)

This experiment should be conducted for the reasons given in Section 4.3.5.

- o PS-29 (Propagation Experiment)

This experiment should be conducted as part of PS-1 for the reasons given in Section 4.3.1.

- o PS-31 (30/20 GHz Propagation Phenomena)

- o PS-33 (30/20 GHz Propagation Experiment)

The objectives of these experiments will be achieved by conducting PS-1 and PS-29.

- o PS-9 (FDMA/TDMA Operation Comparison)

This experiment will not be conducted in Concept I and II because FDMA system is not employed in these two concepts. It will be partially conducted in Concept III.

- o PS-10 (Dynamic Traffic Model - Trunking)

- o PS-21 (Dynamic Traffic Model - CPS)

- o PS-22 (Dynamic Traffic Model - Combined)

These experiments will be partially conducted as they are limited by number of terminals and deployment geometry. The results of these experiments, however, do not justify the high cost since traffic can be predicted with a high degree of certainty.

- o PS-13 (Narrow Band FDMA System)

This experiment will not be conducted in Concept I and II since FDMA system is not employed in these two concepts.

- o PT-4A (Impatt Solid State Transmitter)
- o PT-4B (GaAs FET Transmitter)
PT-4A and 4B will both be conducted in Concept I. In Concepts I, II and III, however, PT-4A will not be conducted and PT-4B will be partially conducted because only GaAsFET type transmitter is incorporated. For the reasons mentioned in Section 4.2.4, both parts of the experiment should be fully conducted in Concept II and III.
- o PT-9 (Baseband Processor Evaluation)
This experiment will be conducted in Concept I, partially conducted in Concept II and will not be conducted in Concept III for the BBP is not employed in Concept III. For the importance of this experiment as mentioned in Section 4.2.6, it should be fully conducted in Concept II, also.
- o PT-3 (Multiple Spot and Scanning Beam Antenna Evaluation)
- o PT-15 (Multiple Scanning Spot Beam Antenna)
These two experiments should be conducted fully in Concept II for the reasons mentioned in Section 4.2.3.
- o PT-20 (Antenna Pointing Accuracy)
It should be conducted in full in all design concepts (see Section 4.2.8).
- o PT-6 (Intersatellite Relay)
- o PT-14 (Intersatellite Link)
- o PT-17 (Intersatellite Link Capability)
- o PT-22 (Intersatellite Link)
All these experiments cannot be conducted in a single flight demonstration.
- o PSAT-1 (Air to Ground Communications)
A separate frequency band should be allocated for A/G communications.
- o PSAT-2 (Spread Spectrum Feasibility)
Spread Spectrum Communication Systems use a much wider bandwidth than that of the data information for transmission. These systems have been preferred by the Military because of their inherent privacy, anti-jam, anti-intercept capabilities.

- o PSAT-4 (Cophasing Parameterization)
- o PSAT-5 (Cophasing Stability Measurements)
These experiments will not be conducted in Concepts II or III, because of scanning antenna design limitations.
- o PSAT-6 (Low Bit Rate FDMA/TDMA)
This experiment should be conducted for the reasons mentioned in Section 4.4.2.
- o PSAT-11 (Adaptive Polarization)
This experiment should be conducted for the reasons mentioned in Section 4.4.5.

Concept I is a full capability CPS scanning beam TDMA and fixed beam SS-TDMA trunking network and Concept II is a reduced throughput capability adaptation of Concept I. We recommend that all the experiments which will be conducted in Concept I should also be conducted in Concept II.

A beacon has not been incorporated in the satellite system. Consequently, all the propagation experiments cannot be conducted. The importance of the propagation experiments has been mentioned in the previous sections.

4.5.2 Hughes

The description of the experiments is very brief and the methodology of performing the experiment is not given. It is mentioned, however, that most of the experiments will be conducted except the experiments which cannot be accommodated in the system, namely:

- PS-4 (Above 40 GHz Propagation)
- PS-23 (C Band and Ku-Band Experiments)
- PSAT-4.5 (Cophasing Experiments)
- PT-15 (30/20 GHz Multiple Scanning Spot Beam Antenna)
- PT-6, 14, 17, 22 (Intersatellite Link)
- PT-9, 12 (Baseband Processor Evaluation)

and the experiments that are not considered to be optimum for mission, namely:

PSAT-3 (Multilevel TWT Control)
PT-4 (GaAs FET Solid State Transmitter)

For the reasons mentioned in the previous section, it is important to conduct several of these experiments such as PSAT-4, PSAT-5, PT-12 and PT-15. PS-4, PS-23, PT-6, PT-14, PT-17 and PT-22 cannot be accommodated in one flight system.

The other experiments that are not considered to be important:

PSAT-3 (Multilevel TWT Control)

A control approach can be simulated in the lab. It is expected that the control method shall be demonstrated as part of the PT-2 experiment.

4.5.3 GE

Scanning beam antenna is not incorporated in the GE design system. Consequently, all the experiments that require a scanning beam antenna cannot be accommodated. GE also claims that the basic experiments' objectives are satisfied but with different requirements/approaches and measurements. There is no elaboration on these differences.

Other reservations mentioned in the GE experiments planning may be justified such as lack of priority and many experiments can be combined, simplified or simulated during ground tests.

The experiments that cannot be accommodated in the design are: PS-3, PS-4, PS-23, PS-31, PT-5, PT-13, PT-14, PT-15, PT-17, PT-22, PSAT-4, PSAT-5, PSAT-10. All the experiments that require scanning beam antenna and baseband processor cannot be performed in whole.

4.5.4 RCA

There is no experiment planning mentioned in the RCA report.

4.5.5 Ford Aerospace

Ford Aerospace proposes two design concepts. Only Configuration 2 utilizes a baseband processor and a beacon package for EHF experiments. Ford failed to address the particular experiments mentioned in the Experiments Planning Document. Certain emphasis has been put on the 44 GHz communications experiment which was discussed before and categorized as a low priority experiment.

The Ford experiment plan was presented in general terms without reference to objectives, variables, evaluation techniques, methods and the means to be used in performing the experiments. It can be assumed, however, that with the utilization of proper instrumentation and monitor devices that the two configurations can accommodate most of the important experiments mentioned in Sections 4.2, 4.3 and 4.4.

SECTION V SYSTEM CONSIDERATIONS

5.1 NETWORK SYNCHRONIZATION AND TIMING

It is essential that any trunking or CPS TDMA concept be demonstrated to a level which verifies the operational synchronization techniques selected for the ground station network. This includes burst assignments synchronous with scanning beams if they are used. Hardware and software functions can be traded off so as to decrease the complexity of the payload, the earth stations or the Master Control Terminal (MCT), depending on whether an open or closed-loop technique is used and whether or not the satellite or the MCT master oscillator is used as the system's reference.

5.1.1 Initial Acquisition

In general, an initial (coarse) acquisition which is open loop is preferable, since it avoids complex search algorithms at the earth stations and minimizes potential interference for new stations entering the TDMA network. For the demonstration flight, adequate open-loop timing accuracy can be provided by the MCT which tracks the satellite position (using turn-around ranging signals from two or more earth stations, e.g., Cleveland and Los Angeles). Satellite radial range errors of about 100 feet, updated every 10 minutes should be adequate for providing worst case network synchronization errors to \pm 200 nanoseconds for all earth stations. Positional error accuracy and update frequency can be improved by additional hardware and software at the MCT at a later time when the operational network is fully deployed, as long as the basic techniques are demonstrable.

5.1.2 Steady-State Synchronization

Steady state synchronization should be closed-loop and can be accomplished effectively by a minor increase in satellite complexity if a Baseband Processor Unit (BPU) is utilized. As indicated in the Motorola BPU design, the time of arrival of each stations uplink is compared with its assigned slot once per frame and the error (early or late) is transmitted by the satellite in the orderwire preamble in that stations downlink burst. The station can then adjust both its

receive (frame frequency) and transmit (frame phase) timing. This concept can easily be extended to the trunking network for payloads that provide the trunking-to-CPS cross-connect via the BPU, such as TRW's Concept I. In the absence of a BPU, station can still maintain steady-state synchronization via a loop-back mode of the IF TDMA switch, but this decreases frame efficiency and increases ground stations hardware.

5.2 CENTRALIZED VS. DECENTRALIZED NETWORK CONTROL

A central network control station must monitor the status of all station interconnectivities as well as the satellite payloads configuration and health (status of redundant subsystems, etc.). This is required for resolving conflicts, maintaining stations availabilities, network reconfigurations, billing, etc. However, real-time control of various functions can be decentralized (either by spot beam or individual station) to a large extent. This can reduce overall hardware/software complexity in an operational system and has a potential for significant cost savings for the demonstration flight. Of course, critical functions which affect major network quality and throughput, if decentralized must have a provision for the MCT to override via satellite order-wire or terrestrial back-up commands.

5.2.1 Network Reconfiguration

Depending on the steady-state and predicted busy-hour changes in traffic demand, it may be possible to allocate spare satellite capacity (resources) by service (CPS or trunking) and/or by beam interconnectivity. Any station, after monitoring the status of its beams unused capacity (this information may be sent downline from the MCT), can add or subtract channels on a non-interfering basis; the MCT is informed of each stations changes. This approach can be used on either FDMA or TDMA concepts.

5.2.2 Rain Response

Link availability can be increased by providing for Forward Error Correction (FEC) code insertion with or without rate reduction (up and down links can be separately encoded if a BPU is utilized), or by uplink and downlink power control (dual-mode HPA's).

The insertion (deletion) of FEC coding or rate reduction can be considered as periodic changes in traffic demand, and resources reserved can be shared as in the network reconfiguration discussion in Section 5.2.1, whereby new calls are entered by the originating stations. To the extent that one or two round-trip delays may be required to set up the FEC or rate-reduction format changes, a means for anticipating this traffic demand such as BER monitoring would be desirable to minimize any periods of lost traffic.

Similarly, uplink power control may be employed under individual station control; care should be exercised in FDMA systems without a BPU that stations limit the amount and duration of increased transmitter power because of the potential for causing power imbalance and intermodulation on the downlink, downlink power control, on the other hand, should probably be controlled by the centralized MCT; however, individual stations may request increased downlink power as required.

5.3 PROVISION FOR ALTERNATE CPS PAYLOAD CONCEPTS

Although the spacecraft design cannot be "optimized" simultaneously for two widely different competing concepts (e.g., narrow scanning - beams for TDMA with Baseband Processing versus wider beam-width contiguous fixed-beams for SS-FDMA, both of which have applicability for CPS users), it may be fruitful to provide for alternate demonstration and testing of the critical technology subsystems for both concepts in a single spacecraft. The two Multi-Beam Antenna (MBA) technology development contractors have both investigated the forming of up to 100 contiguous fixed beams as well as narrower fixed and scanning beams (typically 18 fixed, 6 scanning). Although the MBA contractors have not yet reported on final design concept(s) for the contiguous beams, it appears that there may be a large commonality with the feed elements for both the contiguous and scanned MBA's.

None of the five aerospace contractors have proposed a demonstration system having fixed and scanned narrow beams along with contiguous beam capability. For total CONUS coverage, such an MBA would be quite heavy for even the SUSS-A bus. However, a subset of such an MBA, with partial CONUS coverage, might be conceivable. This would enable demonstration of both TDMA

and FDMA CPS concepts. Such a payload, along with commonality in BFN components, should also be designed to use common LNA's, HPA's (SS or dual-mode TWTA's), up and down converters, etc. The TDMA concept would operate as now proposed with the fixed and scanned narrow beams and the BPU and would be capable of demonstrating a CPS-to-trunking interconnect. The FDMA concept would have selectable bandwidths (tailored to accommodate the CPS throughput rate of 64 or 880 kbps up to a full video FM channel of 36 MHz); it may also be desirable to demonstrate selective FDM routing (with an additional two millisecond delay) through the BPU.

5.4 OTHER CONSIDERATIONS

Based on Western Union's perception of operational system requirements, additional demonstration system design features should be considered in order to establish the scalability capability of the demonstration system to an operational system with a high degree of confidence. In spite of the fact that various concepts proposed by the Contractors are sound and well conceived, the designs are based on ideal and simplified assumptions. We, therefore, recommend that the following design considerations be addressed to ensure smooth transition from a demonstration system to an operational system.

5.4.1 Capacity Considerations

The projected requirements of the three types of carriers and satellite capacity requirements for operational systems for the year 2000 time frame has been developed in Reference 3. A comparison of the projected traffic requirement and demonstration flight throughput indicates that extensive frequency reuse will be required to meet the demand. The frequency reuse in the demonstration satellite is very limited and a frequency reuse factor of four or larger will be required to meet the projected traffic requirement. The design of antenna subsystems should, therefore, consider the following:

- Antenna subsystem scalability to increase the number of beams to twenty (20) in an operational system.

- Consider the antenna design for one steerable trunking (or variable frequency band) beam to provide for measurement of cochannel interference and cross-polarization isolation.
- A beam topology in view of diverse traffic requirements that various beams will be required to support. The frequency reuse factor using the bandwidth assignment to support a non-uniform traffic will be significantly worse as compared to the frequency reuse factor obtained by assuming a uniformly assigned bandwidth to each beam. A beam topology using beam combining for lightly loaded beams will result in more uniformly distributed traffic. Scanning beams should also have coverage areas of equal traffic demands. A well designed beam/frequency plan will result in balanced bandwidths for the beams and frequency bands can be segmented such that the cochannel beam interference is significantly reduced. Furthermore, the capacity of some individual beams will probably not be filled until late in the satellite's useful life. The arrangement of beams, frequency plans, routing and switching plans are intimately tied to specific network characteristics which must be taken into account for the design of an operational system. The complexity of frequency planning and what can be accomplished to optimize the system by the following:
 - Beam combining to balance the traffic
 - Minimization of co-channel interference
 - Distribution of heavy rain zone attenuation effects.

5.4.2 Flexibility Considerations

In an operational multi-beam satellite system the traffic handled by various beams will be highly diverse in both average and short term demands. The traffic density ratio for a highly saturated beam to a sparsely saturated beam could be as high as 20:1 or more. For example, a beam servicing New York may be the first one to fully saturate before the end of satellite life where as a beam servicing

Rocky Mountain states may be required to support a much lighter traffic. Such a large disparity of traffic requirements should be taken into account in the satellite design. One can also envision the case of a lightly loaded beam where a large change of demand may occur, for example, one or more 40 mbps video conference request may appear in a beam. Consequently, flexibility is an important requirement for the satellite switching arrangement. The system dynamics is an important aspect of an operational system.

5.4.3 Satellite Location

It is assumed that the satellite will be located around 100° West longitude, which is highly desirable but not assured due to FCC regulation and other constraints. This case does not represent the worst case situation. For trunking nodes high availability is of fundamental importance and satellite location has serious effects on the rain attenuation and scan loss as the satellite is moved towards the extremes of the useable orbital arc.

5.4.4 Adaptive Rain Margin

A number of options, e.g., ground power control, satellite power diversity, rate diversity, FEC and a combination thereof have been proposed to provide the adaptive rain margins specified in the SOW to achieve a given availability. A strategy should be considered so as to perturb the system to a minimum. Furthermore, since rain attenuation characteristics are quite different for various regions, a strategy based on rain compensation for worst case may not be appropriate for other regions.

Although more than one parameter may be used for rain attenuation, use of uplink and/or downlink power control is relatively simple to implement without requiring network coordination. Thus, it may be preferable to achieve from 0.99 to 0.999 availability by power control alone (this happens 1% of the time). Availability from 0.999 to 0.9995 or higher may be achieved by FEC or rate reduction, both of which require network coordination and possibly burst assignment changes (this occurs about 0.1% of the time). Clearly, a graduated strategy based on particular requirement of fade compensation will be more appropriate.

Some design reports suggest $\frac{1}{2}$ rate code (5.5 db SNR improvement), half data rate (3 db SNR improvement) result in a composite improvement of 8.5 db in SNR, whereas a data rate reduction by one order of magnitude gives 10.0 db improvement in SNR. In the second case with the change of only one parameter exceeds the improvement given by the change of two parameters. For CPS such a data reduction should have no serious effect on the efficiency. The CPS throughput is only a small portion of the total throughput and because of small rain cell size only a few stations can be expected to fade simultaneously. Thus, choosing an optimum strategy for adaptive rain margin can provide sufficiently large rain margins and minimize perturbing the network. A sufficiently large clear weather margin will also be beneficial to overcome small environmental perturbations and will reduce the number of CPS stations requiring a change of quiescent parameters.

5.4.5 Power Control

In order to have a meaningful power boost, it should match the rain attenuation to the extent possible. The power boost desired is, therefore, a function of the satellite location and the rain zone in which the stations are located.

5.4.6 Network Synchronization and Control

Although the proposed synchronization concepts are well conceived, the control system aspects of the synchronization tracking system require further study. The tracking loops in the synchronization tracking system will have second or higher order characteristics. Due to the round trip satellite transport delay and integration delay in the phase locked loops, it is quite possible that unless the gain and phase characteristics of control loops are properly chosen, the synchronization subsystem may be marginally stable. Since the round trip propagation delay contributes to the instability of the control loops, an increase in integration time, while reducing the stability margin, has the beneficial effect of reducing the steady state error. The affect of propagation delay in locating the zeros of open loop transfer function, allowable loop gains, and integration time to reduce the tracking error should be studied further.

Trade off analysis should be performed to define the relative advantages of open loop vs. close loop systems with respect to cost, complexity, and system operation, particularly CPS earth station costs.

5.4.7 Satellite Switch Traffic Optimization

Efficient transmission (maximum throughput with minimum switching) is an important consideration in a satellite switched TDMA system. While it is intuitively clear that maximum throughput of the SS-TDMA will occur when all the beams have equal traffic, an algorithm such as the Greedy Algorithm should be developed for an operational system to optimize system throughput.

5.4.8 Network Interconnectivity

The network connectivity for a high Grade of Service (GOS) is an important aspect of an operational system. A typical set of incrementally stepped guidelines is given below as an example.

- All traffic is pre-assigned, with changes to occur only by preplanned and presumably operator intervention which is a relatively slow process. This step is characterized by total demand between each pair of zones being less than the bandwidth assigned to that pair of zones. There, the design criterion is the achievement of these interconnectivity demands with a minimum number of satellite switch modes.
- Introduction of a dynamic assignment operation - As the system matures, towards the later part of the satellite's useful life the traffic demand is characterized by peak demand being larger than the channel capacity while the average demand is still below channel capacity. Such a scenario can be easily envisioned for a beam servicing New York, which most likely will be the first one to saturate. Furthermore, new demand may occur at a rate considerably larger than the reciprocal of a typical call duration. Under these conditions the design should strive to achieve a good Grade of Service (GOS). A dynamic assignment mode of operation, from Grade of Service point of

view, as has been recognized in telephony where GOS is the measure of performance merits further investigation.

5.4.9 Ground Station Sizing

For the demonstration satellite, in general five (5) meter and three (3) meter earth stations have been proposed. For the 30/20 GHz operational satellite system the earth station sizing and HPA sizing may involve consideration of and optimization over a range of system parameters. These include:

1. The need for large, medium and small capacity earth stations with different rain availability requirements.
2. Different rain statistics in different locations in the CONUS.
3. Variation in the satellite EIRP and G/T over the CONUS.
4. Possible use of different burst rates for small, medium and large earth stations.

It is desired that the utilization efficiency of the TDMA system be as high as possible. Inefficiency due to guard times, burst preambles, coding redundancy and other sources should be kept to a minimum consistent with other system requirements.

Making assumptions regarding satellite and earth station HPA back-off interference losses, losses due to nonlinearities, AM to AM and AM to PM conversion effects, one can derive uplink and downlink C/N equations depending only on satellite EIRP and G/T, earth station HPA power and earth station antenna diameter. The uplink and downlink C/N should be large enough to assure a threshold BER, i.e., 10^{-4} for voice, 10^{-7} or better for data communication, is met. Use of brute force to achieve required system performance can result in large and expensive stations. This is particularly relevant to CPS service which most likely will form a broad base for revenues to achieve a satisfactory return on investment.

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